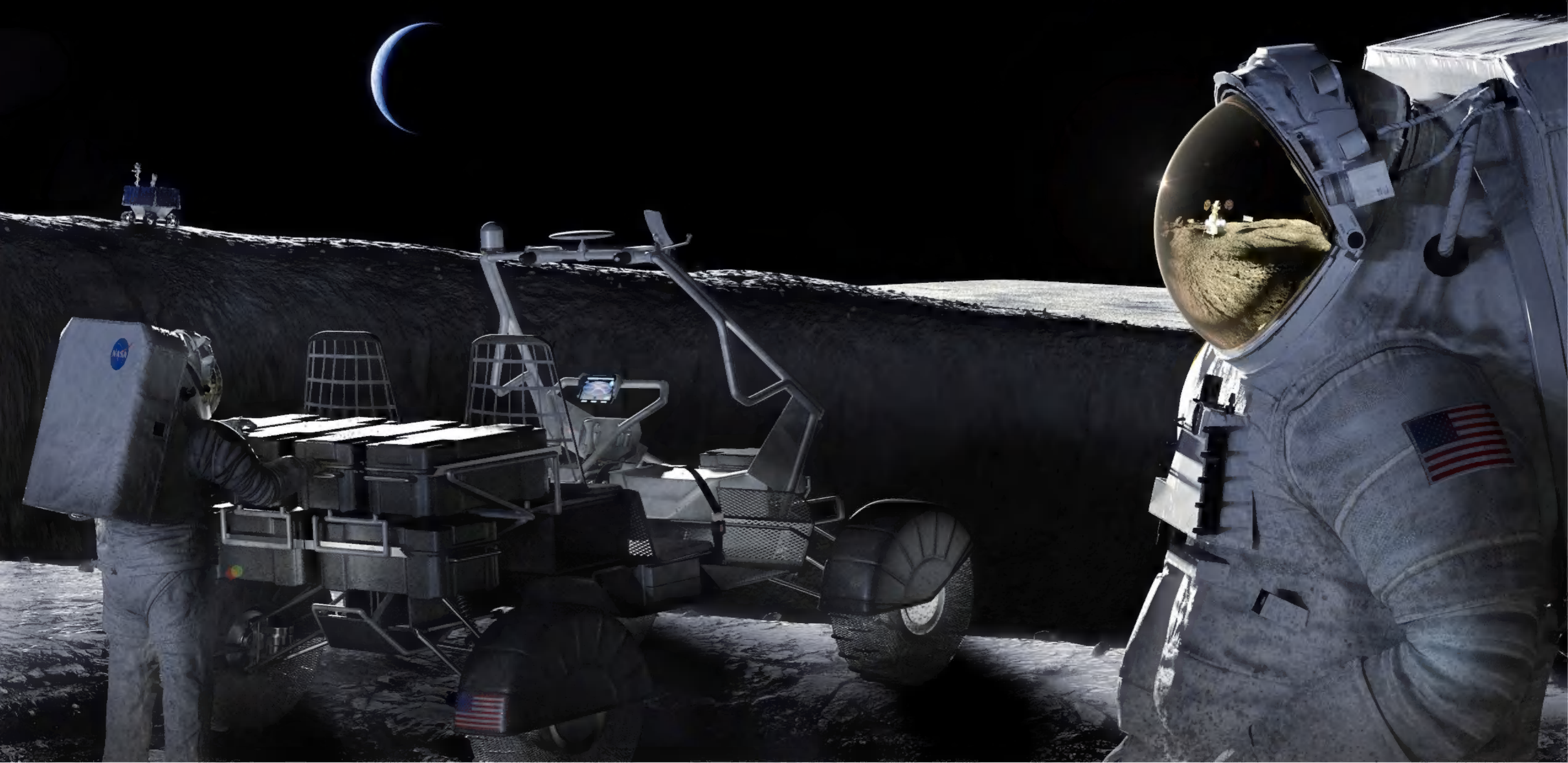
National Aeronautics and Space Administration

ARTEMIS PLAN

NASA's Lunar Exploration Program Overview

September 2020



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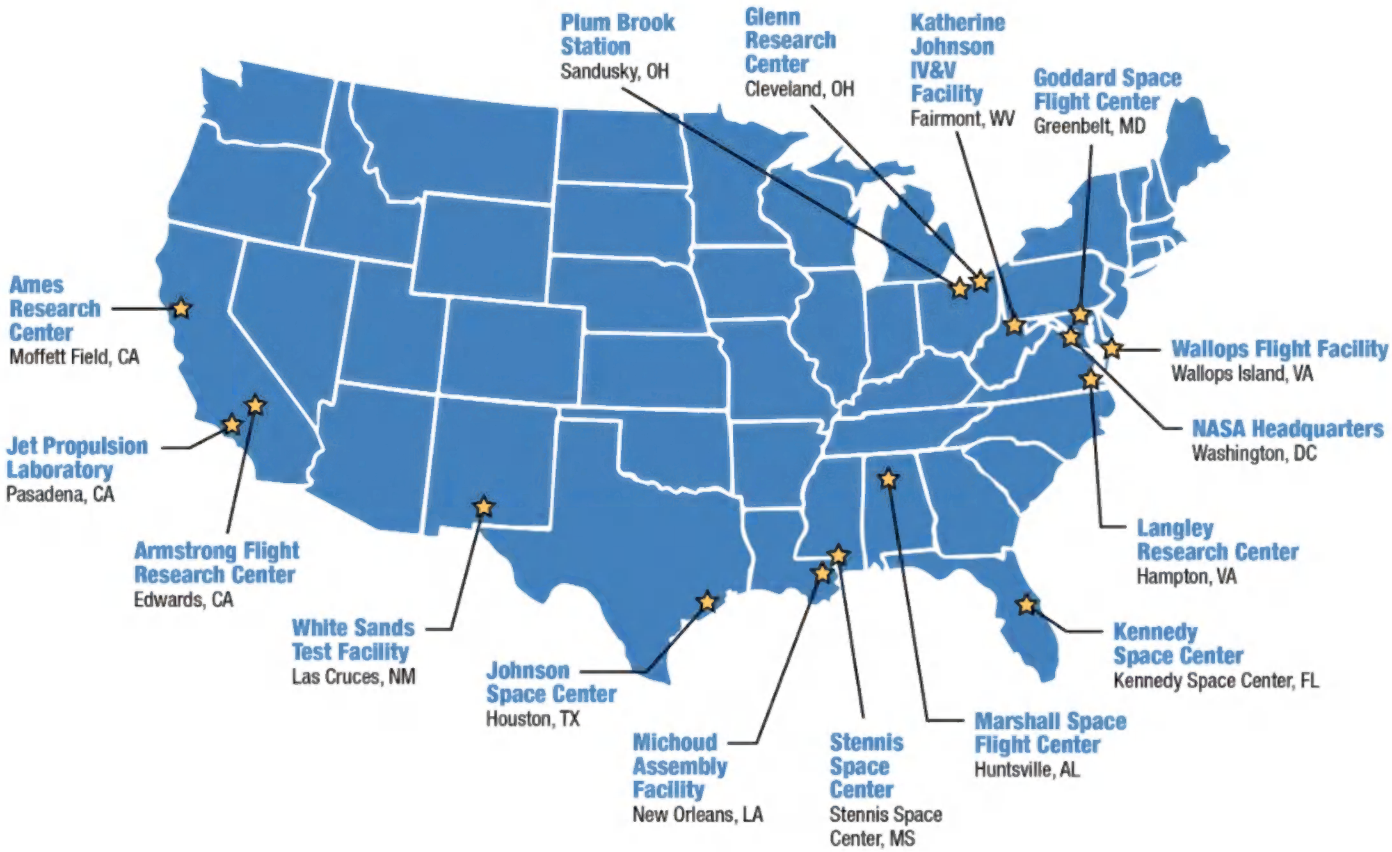
Key Artemis Contributions by NASA Center



Suppliers and small businesses across America have made contributions to the success of NASA's Artemis program, with private companies hard at work on innovations that will help establish a sustainable human presence at the Moon. The Artemis endeavor also extends beyond our borders.

These missions are critical to the space economy, fueling new industries and technologies, supporting job growth, and furthering the demand for a highly skilled workforce.

For detailed information about NASA's partners and where to find them, visit the Artemis partners map at www.nasa.gov/content/artemis-partners.

Ames Research Center

- Volatiles Investigating Polar Exploration Rover (VIPER)
- Orion thermal protection system
- Wind tunnel testing and computational analysis for SLS and commercial launch vehicles
- Human-autonomous systems
- Flight simulators

Armstrong Flight Research Center

- Orion flight test system integration
- Orion abort test booster
- Entry, descent, and landing demonstrations
- Suborbital flight tests for lunar lander technologies

Glenn Research Center

- Gateway power and propulsion element lead
- Orion European Service Module management and testing
- Surface and spacecraft power (fission, radioisotope and solar)
- Cognitive and Quantum Communications
- Cryogenic fluid management
- In-situ resource utilization
- Simulated in-space environmental testing
- Plum Brook Station management

Goddard Space Flight Center

- Lunar Reconnaissance Orbiter
- Astronaut science operations training
- Heliophysics, space weather, radiation, astronaut and hardware support
- Space communications and navigation
- In-space servicing and assembly
- Software and avionics
- Moon and Mars fundamental and applied science
- Wallops Flight Facility management

Headquarters

- Agency stakeholder engagement
- Directorate management and integration
- Program/project formulation
- Lunar Surface Innovation Initiative

Jet Propulsion Laboratory

- Orion Systems Engineering & Integration
- Independent validation of Orion thermal protection system and parachutes
- Perseverance Rover: Robotic planetary sampling, spacesuit materials resilience
- Gateway electric thruster development
- Advanced spacecraft environmental monitoring
- Terrain-Relative Navigation

Johnson Space Center

- Orion Program
- Gateway Program
- Gateway habitation and logistics outpost
- Commercial Lunar Payload Services
- Astronaut office
- Mission Control Center
- Flight operations and execution
- Human health and performance, exploration medical capabilities
- Exploration spacesuit (xEMU) development and first build
- Lunar Terrain Vehicle
- Precision landing/hazard avoidance
- Lunar sample curation

Kennedy Space Center

- Exploration Ground Systems
- Ground Processing, Launch, Landing, and Recovery Planning and Operations
- Gateway Logistics Services
- Launch Control Center
- Commercial launch vehicle services and acquisition

Langley Research Center

- Orion Launch Abort System
- Orion water impact testing
- Navigation Doppler Lidar
- Strategy, Architectures, and Systems Engineering
- Scientifically Calibrated In-Flight Imagery for Artemis I launch and Orion reentry
- Radiation protection

Marshall Space Flight Center

- Human Landing System Program
- Space Launch System Program
- SLS Core Stage development, construction, structural testing
- SLS Core Stage Structural Testing
- Artemis I secondary payloads
- Launch Vehicle Stage Adapter (LVSA) and Orion Stage Adapter (OSA/MSA)
- Industry habitation concept development
- Michoud Assembly Facility management

Stennis Space Center

- SLS core stage testing
- SLS RS-25 engine testing

As of September 2020

Foreword by Jim Bridenstine

Pushing the boundaries of space exploration, science, and technology once again, America is on the verge of exploring more of the Moon than ever before. This new era of lunar exploration is called Artemis. Named after the twin sister of Apollo, she is the Goddess of the Moon, and we are the Artemis Generation.

NASA Administrator Jim Bridenstine

NASA is building a coalition of partnerships with industry, nations and academia that will help us get to the Moon quickly and sustainably, together. Our work to catalyze the U.S. space economy with public-private partnerships has made it possible to accomplish more than ever before. The budget we need to achieve everything laid out in this plan represents bipartisan support from the Congress.

Today, NASA is delivering more missions, more science, and more innovation at a better value for the American taxpayer than at any point in the agency's history and with half the buying power than 1964, when Apollo development was at its peak. We thank the President, the Congress, the American taxpayers, and the emerging space industry for the combined efforts to strengthen our nation's space program.

Under the Artemis program, humanity will explore regions of the Moon never visited before, uniting people around the unknown, the never seen, and the once impossible. We will return to the Moon robotically beginning next year, send astronauts to the surface within four years, and build a long-term presence on the Moon by the end of the decade.

I am proud to share NASA's Artemis Plan—this is how we will go to the Moon once again. And how we will use the Moon as the stepping stone for our next greatest leap—human exploration of Mars.

We are going, and we go together. Ad lunam!

Jim Bridenstine

Introduction

America has entered a new era of exploration. NASA's Artemis program will lead humanity forward to the Moon and prepare us for the next giant leap, the exploration of Mars. It has been almost 50 years since astronauts last walked on the lunar surface during the Apollo program, and since then the robotic exploration of deep space has seen decades of technological advancement and scientific discoveries. For the last 20 years, humans have continuously lived and worked aboard the International Space Station 250 miles above Earth, preparing for the day we move farther into the solar system.

Sending human explorers 250,000 miles to the Moon, then 140 million miles to Mars, requires a bold vision, effective program management, funding for modern systems development and mission operations, and support from all corners of our great nation as well as our partners across the globe.

NASA has been fine-tuning the plan to achieve that bold vision since the president called on the agency in December 2017 to lead a human return to the Moon and beyond with commercial and international partners. Two years later, he challenged us yet again, this time to send the first woman and next man to the Moon within five years. NASA is implementing the Artemis program to achieve those goals, and this document lays out the agency's Moon to Mars exploration approach explaining how we will do it.

The Moon plan is twofold: it's focused on achieving the goal of an initial human landing by 2024 with acceptable technical risks, while simultaneously working toward sustainable lunar exploration in the mid- to late 2020s.

2024 is not an arbitrary date. It is the most ambitious date possible, and our success at the Moon, and later, at Mars, will be grounded in our national goals and robust capabilities. The United States leads in space exploration now; however, as more countries and companies take aim at the Moon, America needs the earliest possible landing to maintain and build on that leadership, as well as to prepare for a historic first human mission to Mars.

Landing astronauts on the Moon within four years will better focus this global initiative on the engineering, technology development, and process improvements necessary to safely and successfully carry out sustained human exploration of the Moon. It also paves the way for U.S. commercial companies and international partners to further contribute to the exploration and development of the Moon.

We need several years in orbit and on the surface of the Moon to build operational confidence for conducting long-term work and supporting life away from Earth before we can embark on the first multi-year human mission to Mars. The sooner we get to the Moon, the sooner we get American astronauts to Mars.

We need to act fast to make this vision a reality, and a crewed lunar landing by 2024 is the key to a successful Moon to Mars exploration approach. Our next lunar landing paves the way for a new and sustainable lunar economy—one where U.S. companies and international partners will benefit from and build on what we learn.

Early Artemis Missions

With the powerful Space Launch System (SLS) rocket and Orion spacecraft nearing the end of testing and development, the agency has the foundation needed to send humans back to lunar orbit. In preparation for the safest earliest possible lunar landing, NASA seeks to make full use of early Artemis missions through additional testing for Orion and the Human Landing System (HLS) when possible.

The Gateway is a critical component of the agency's sustainable lunar operations. NASA will integrate the first two pieces on Earth, launching the Power and Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO) together in 2023 on a single rocket, followed by a commercial logistics supply launch.

In 2024, Orion will deliver its crew to lunar orbit. The commercially developed lander that will take the crew to the lunar surface will be capable of docking directly to Orion for crew transfer for early Artemis missions, but NASA is maintaining flexibility for optional docking to the Gateway. On the surface, the crew will wear the new exploration extravehicular mobility unit or xEMU spacesuit as they explore the surface for about a week before returning to Orion for the trip home to Earth.

Sustainable Artemis Missions

On later Artemis missions crew will arrive at the Gateway aboard Orion. On the Gateway, they will be able to conduct research and take trips down to the surface. NASA will work with Artemis providers to ensure spacecraft are built to international interoperability standards with as many reusable components as possible for long-term sustainability at the Moon.

Long-standing International Space Station partners are eager to join NASA in lunar orbit. The Canadian Space Agency (CSA) has committed to providing advanced robotics for the Gateway, and ESA (European Space Agency) plans to provide the International Habitat (IHab) and the ESPRIT module, which will deliver additional communications capabilities, a science airlock for deploying science payloads and CubeSats, and refueling of the Gateway. The Japan Aerospace Exploration Agency (JAXA) plans to contribute habitation components and logistics resupply. The Russian Space Agency (Roscosmos) has expressed interest in cooperation on Gateway as well.

At the lunar South Pole, NASA and its partners will develop an Artemis Base Camp to support longer expeditions on the lunar surface. Planned Base Camp elements include a lunar terrain vehicle (LTV, or unpressurized rover), a habitable mobility platform (pressurized rover), a lunar foundation habitation module, power systems, ad in-situ resource utilization systems.

This incremental build-up of capabilities on and around the Moon is essential to establishing long-term exploration of Earth's nearest neighbor and preparing for human exploration of Mars.

Chapter 1: Setting Humanity on a Sustainable Course to the Moon

The Artemis program builds on a half-century of experience and preparation to establish a robust human-robotic presence on and around the Moon. With clear direction from the White House, coordination among the reestablished National Space Council, strong bipartisan support in Congress, and robust participation from industry and international partnerships, Artemis is a globally unifying endeavor.

America will lead the monumental shift that frees humanity from our innate bonds to Earth. This is the decade in which the Artemis Generation will teach us how to live on other worlds.

Presidential Memorandum on Reinvigorating America's Human Space Exploration Program

★ ★ ★

"Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations."

—Excerpt, Space Policy Directive-1, December 11, 2017

The Basis for a Lunar Architecture

NASA was ready for Space Policy Directive-1, the call from the President to return to the Moon and get ready for Mars, and was already prepared to offer architectural and hardware solutions to leverage the core deep space transportation systems—the SLS rocket, the Orion spacecraft, and the supporting Exploration Ground Systems (EGS)—to return humans to the Moon for the first time in more than 50 years.

Through partnerships with U.S. industry, NASA was already developing 21st century deep space habitation capabilities and investing in lunar lander technologies. Ongoing spacesuit upgrades have resulted in a lunar surface suit that affords more frequent spacewalks through improved safety features, custom fitting, simplified maintenance, and better communications. A cross-agency

architecture team also had been formulating plans for a Gateway orbiting the Moon. This plan garnered significant support from international partners and was reflected in the Global Exploration Roadmap as a collaborative effort that would "open the space frontier for human exploration of the Moon, Mars and asteroids as we expand human exploration and commerce into deep space."

In 2018, with support from the highest-level national decision makers, NASA proposed a plan to return humans to the lunar surface by 2028. This plan included the Gateway from which human landers could be deployed. There was strong international support for the orbiting lunar outpost, and International Space Station partners proposed additional capabilities they could contribute. The Gateway program advanced from formulation to program status in late 2018.

SCIENCE

Initial investigations delivered by CLPS providers will study the lunar surface and resources at the lunar poles.

NASA originally selected nine CLPS providers, but as the need to deliver heavier payloads became apparent, the agency later added five more companies.

In May 2019, NASA awarded the first two task awards for 12 instrument deliveries to Astrobotic (Pittsburgh, PA) and Intuitive Machines (Houston, TX). Those initial flights are launching in 2021, and NASA is planning for two deliveries per year thereafter.

NASA also established the Commercial Lunar Payload Services or CLPS initiative in 2018, encouraging the U.S. commercial space industry to introduce new lander technologies to deliver NASA and commercial payloads to the surface of the Moon.

With 14 CLPS providers currently on contract and eligible to bid on payload deliveries to the Moon, NASA solicits bids from the companies as needed and awards surface task orders for lunar surface deliveries. The agency has already awarded multiple deliveries and assigned payloads to flights in 2021 as well as the first of two planned deliveries slated for 2022. A task order was awarded in June 2020 to Astrobotic of Pittsburgh, Pennsylvania, to deliver NASA's Volatiles Investigating Polar Exploration Rover or VIPER in 2023. The agency plans to send science instruments and technology experiments to the surface at least twice per year on CLPS flights.

NASA has already selected more than two dozen instruments to study the Moon and test new technologies for these early CLPS flights, including VIPER. The agency also has announced a new process to build an internal database of future lunar surface investigations. Through the Payloads and Research Investigations on the Surface of the Moon or PRISM, NASA is interested in investigations that maximize basic and applied science and technology demonstrations at different lunar locations, as well as individual investigation components that would be valuable at multiple locations. The agency will use the PRISM information to inform the manifests of future CLPS deliveries beginning in 2023. The agency will periodically open up PRISM requests for information to collect new ideas and investigations eligible for future CLPS flight opportunities.

Meanwhile in 2018, NASA began the acquisition process for commercially provided Human Landing Systems (HLS) to meet the goal of sending humans back to the Moon. By harnessing new technologies and spurring competitive innovation, NASA will work with commercial partners to

design and develop an HLS capable of accessing any part of the Moon and reusing sections of the system to increase affordability.

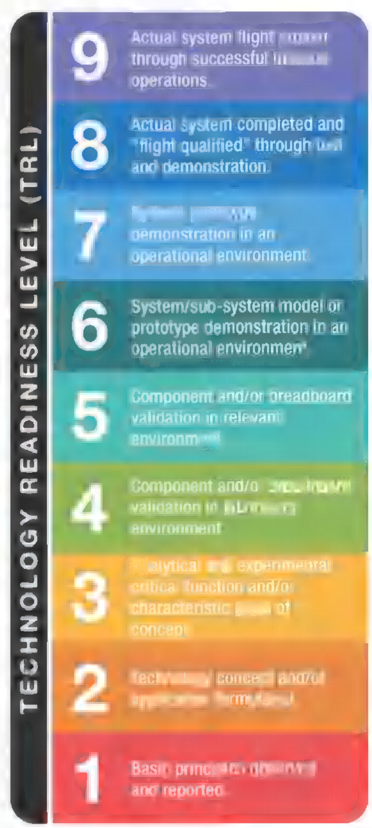
The team issued a Broad Agency Announcement (BAA) (NextSTEP Appendix E) to U.S. industry, seeking HLS studies, risk reduction, development, and demonstration. Proposals were due March 25, 2019, one day before Vice President Pence issued a new challenge to NASA: land the first woman and next man on the Moon by 2024—four years earlier than originally planned. NASA moved quickly to respond to the Vice President's challenge.

By May 2019, NASA had selected 11 companies across eight states under NextSTEP Appendix E to conduct studies and produce system-level prototypes to reduce risk and advance human lander technologies. Appendix E immediately allowed NASA to engage with commercial industry on early designs and how to best set up a rapid development approach to meet the 2024 objectives.

In response to the new, accelerated charge to the Moon, the agency issued a draft solicitation (NextSTEP Appendix H) in July 2019, this time seeking feedback on the development and demonstration of an integrated HLS to deliver humans to the lunar surface by 2024 and for the development and demonstration of a more sustainable HLS by 2026. Following a second draft in August and after addressing more than 1,150 comments, the final Appendix H solicitation was issued in October 2019. Awards were made to three companies in spring 2020.

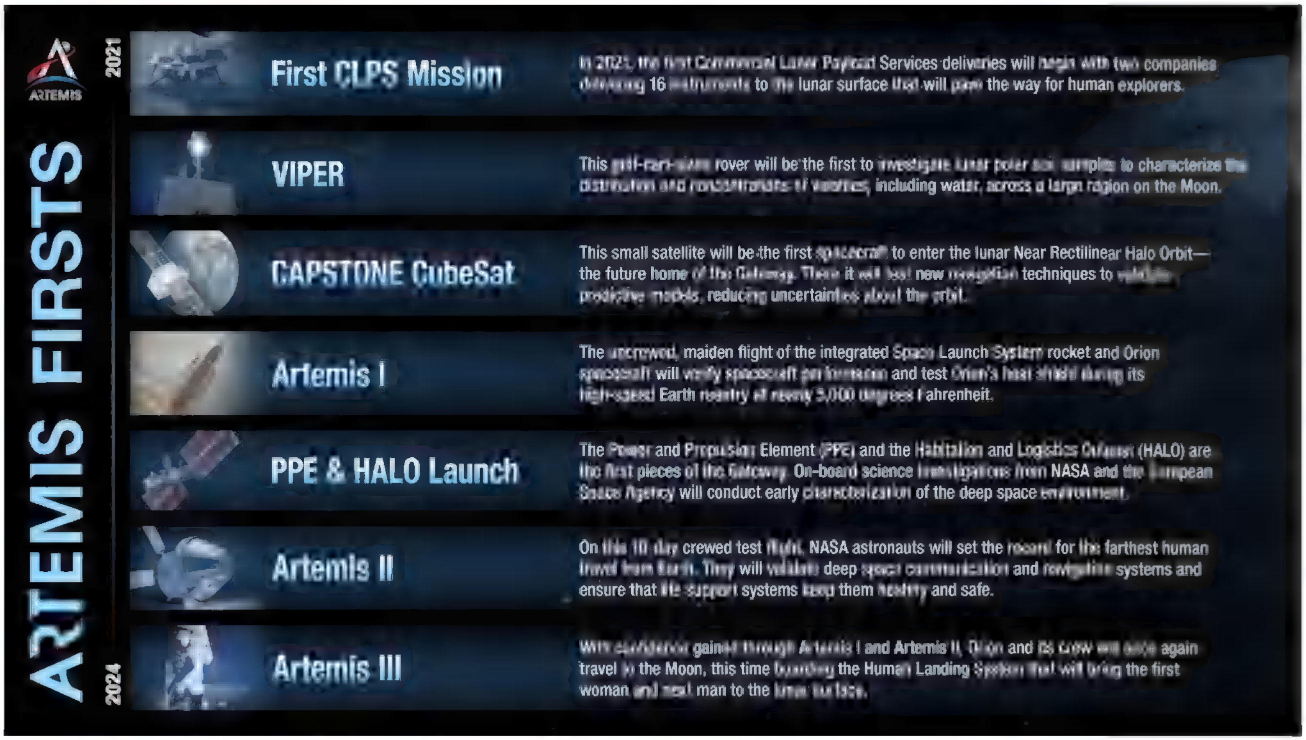
Program Status Assessment

In January 2020, NASA's Human Exploration and Operations Mission Directorate (HEOMD) chartered a program status assessment (PSA) of activities planned to achieve a human landing on the Moon by 2024. The assessment comprised teams of NASA personnel and outside aerospace experts who examined the overall early Artemis architecture, including Orion, SLS, Exploration Ground Systems (EGS), Gateway, HLS, and system engineering and cross-program integration. Members of the PSA teams examined management and integration across programs, schedule risks, technical risks, technical systems engineering integration, and test program thoroughness.



Following the six-week assessment, PSA findings indicated that the Artemis III approach that was baselined for the original 2028 landing timeline—and therefore the schedule to meet the goal of landing the first woman and next man on the Moon by 2024—was significantly dependent on new technology maturation. Based on the findings, NASA is conducting studies with the HLS vendors to investigate where high TRL systems may improve schedule for Artemis III.

Another change resulting from the PSA findings included launching the Gateway's PPE and HALO together on a single rocket. Initially, NASA was planning separate launches in 2022 (PPE) and 2023 (HALO) and subsequent autonomous rendezvous and docking in lunar orbit. Integrating PPE and HALO on the ground is a cost-effective approach to reducing technical risk and enhancing mission success by eliminating the need for two segments to dock in deep space. While in lunar orbit, this early Gateway will demonstrate its unique orbit and operate science payloads in deep space.



A snapshot of "firsts" to be achieved through the Artemis program.

Chapter 2: Landing Humans on the Moon in 2024

The foundation for our return to the Moon is NASA's deep space transportation system: the Orion spacecraft, SLS rocket, the HLS, and the EGS facilities that include a modernized spaceport. The Orion spacecraft, powered by a service module provided by ESA (the European Space Agency), has been specifically designed for deep space human operations for up to four crew. The SLS rocket is the human rated heavy-lift rocket designed to launch Orion and send it on missions to the Moon.

Next year, science and technology will lead our return to the Moon as we see the first payloads delivered to the lunar surface aboard CLPS provider landers and 13 CubeSats deployed from the SLS during Artemis I—five of which will return lunar data. Human exploration under the Artemis program will begin with the crewed flight test of SLS and Orion on Artemis II in 2023. In this same time frame, NASA and its commercial HLS partners also plan to conduct in-space flight testing of the lander system, including potential tests to the lunar surface. NASA's goal is to conduct in-space testing of every possible hardware, software, and operational system required for Artemis III prior to the mission in 2024.

Artemis I and Mission Readiness

The Artemis I SLS rocket will launch an uncrewed Orion into Earth orbit, placing it on a path toward a lunar distant retrograde orbit, where it will travel 40,000 miles beyond the Moon, or a total of about 280,000 miles from Earth before returning home. This crucial flight test will demonstrate the performance of the SLS rocket on its maiden flight and gather engineering data throughout before Orion returns on a high-speed Earth reentry at Mach 32, or 24,500 miles per hour. The high speed lunar velocity reentry is the top mission priority and a necessary test of the heat shield's performance as it enters Earth's atmosphere, heating to nearly 5,000 degrees Fahrenheit—about half as hot as the surface of the sun—before splashing down in the Pacific Ocean for retrieval and post-flight engineering assessment.

For this uncrewed configuration, engineering equipment will fly in place of astronaut-essential elements. Instead of the cockpit displays and controls and life support systems that will fly on the first crewed flight, this first flight will carry the data-gathering tools needed to validate performance and compare predictive models with actual flight data. Over the course of the four-to-six-week mission, Orion will travel more than 1.4 million miles prior to returning to Earth, surpassing Apollo 13's record for distance traveled from Earth in a spacecraft designed for humans. This mission will also deploy 13 CubeSats to conduct new scientific investigations and new technology demonstrations that will improve our knowledge of the deep space environment, while engaging a broader set of universities, international partners, and private companies in lunar exploration than ever before on a single mission.

SCIENCE

Artemis I will leverage excess volume on the massive SLS rocket to carry 13 CubeSats to deep space and deploy them to conduct science and technology research.

These "hitchhiker" payloads are provided by NASA, U.S. companies, academic institutions and international partners. Five of them will return important data about the lunar environment to inform future Artemis missions.

Space Launch System Mock Up arrives at Kennedy for Testing. NASA's Pegasus Barge arrived at the Launch Complex 39 turn basin wharf at Kennedy Space Center in Florida to make its first delivery to Kennedy in support of the agency's Artemis missions. The upgraded 310-foot-long barge arrived September 27, 2019, ferrying the 212-foot-long Space Launch System rocket core stage pathfinder. Weighing in at 228,000 pounds, the Pathfinder is a full-scale mock-up of the rocket's core stage and will be used to validate ground support equipment and demonstrate it can be integrated with Kennedy facilities.

Preparations for Artemis I are well underway. Production is complete for the SLS engines—comprising four RS-25 liquid rocket engines, two solid rocket boosters, the massive core stage, and the interim cryogenic propulsion stage that provides Orion's final push toward the Moon—and all are completing preflight tests. Beyond significant ground tests when NASA has fired elements of the rocket from test stands in Mississippi, Utah, and Alabama, a fully integrated series of ground tests will take place at Kennedy Space Center before a final Flight Readiness Review prior to the Artemis I launch.

Orion's maiden flight test, Exploration Flight Test-1, flew on December 5, 2014. The 4.5-hour mission demonstrated Orion's space-worthiness in a high-Earth orbit, tested the spacecraft's heat shield to the extent possible during reentry into the Earth's atmosphere, and proved the capsule's recovery systems. Although EFT-1 didn't include a crew, the Orion capsule flew higher and faster than any spacecraft meant to carry humans in more than 40 years.

NASA completed the final series of Orion parachute tests in September 2018. The system includes 11 parachutes that begin deploying at almost five miles in altitude. Over the course of eight qualification tests at the U.S. Army's Yuma Proving Ground in Arizona, engineers have evaluated the performance of Orion's parachute system during normal landing sequences as well as numerous failure scenarios and a variety of potential aerodynamic conditions to ensure astronauts can return safely from deep space missions.

In 2019, NASA conducted a successful test known as Ascent Abort-2, which tested the Orion launch abort system that sits atop Orion at launch and during ascent. If an emergency occurs during launch, the launch abort system pulls Orion and its crew away from the rocket to land in the Atlantic Ocean. The three-minute test proved that Orion's launch abort system can outrun a speeding rocket during high-stress aerodynamic conditions and pull astronauts to safety if an emergency occurs during launch.

Additional pre-flight testing details are documented in Appendix 4, *Artemis Flight Readiness*.

A launch abort system with a test version of Orion attached soars upward on NASA's Ascent Abort-2 (AA-2) flight test atop a Northrop Grumman provided booster on July 2, 2019.

The Orion crew module for the Artemis I mission has been fully assembled, tested, and integrated with the European service module. The service module, built by ESA, provides most of the propulsion, power, and cooling systems for the crew module where astronauts will live and work during Artemis missions. The integrated spacecraft successfully completed simulated in-space environments testing, verifying that Orion's systems will perform as expected during Artemis missions. Inside the world's largest vacuum chamber, the spacecraft was subjected to the extreme electromagnetic conditions and temperatures (-250 to 200 degrees Fahrenheit) of space. The campaign was completed ahead of schedule, and the spacecraft has since returned to the space coast for final preparations ahead of integration with the SLS rocket.

NASA's ground systems team has modified the infrastructure and ground support equipment necessary to launch Artemis missions and recover Orion. The mobile launcher has undergone integrated testing inside the Vehicle Assembly Building and at the newly renovated Launch Pad 39B, validating it can communicate effectively with the facility systems and ground systems to perform appropriately during launch.

The EGS team responsible for carrying out launch operations has performed training simulations inside firing room 1 to certify the team is ready for launch and can work through any type of issue in real time. Teams have also practiced offloading, maneuvering, and stacking the 212-foot-long SLS core stage using a full-scale mock-up called a pathfinder.

Artemis II

With Artemis II, the first crewed flight of SLS and Orion will send four astronauts to the lunar environment for the first time in more than 50 years. This will be the Artemis Generation's "Apollo 8 moment," when the astronauts aboard Orion will capture the full globe of the Earth from afar, as a backdrop to the Moon.

With confidence based on the Artemis I mission and the thousands of hours put into prior flight and ground testing, the Artemis II crew will board Orion atop the SLS for an approximate 10-day mission where they will set a record for the farthest human travel beyond the far side of the Moon in a hybrid free return trajectory.

The SLS rocket will launch the crew aboard Orion, and the spacecraft will make two orbits around Earth before committing to the trip to the Moon. Orion will first reach an initial insertion orbit at an altitude of 115 by 1,800 miles and the elliptical orbit will last approximately 90 minutes with the perigee adjusted via the rocket's first firing of the interim cryogenic propulsion stage (ICPS). After the first orbit, the rocket's ICPS will again provide the thrust to raise Orion into a high-Earth orbit (HEO), flying in an ellipse for approximately 42 hours between 200 and 59,000 miles above Earth.

After reaching HEO, Orion will separate from the ICPS, and the expended stage will have one final use before it is disposed through Earth's atmosphere—the crew will use it as a target for a proximity operations demonstration. In this demonstration, the astronauts will pilot Orion's flight path and orientation in manual mode. The crew will use onboard cameras and the view from the spacecraft's windows to line up with the ICPS as they approach and back away from the stage to assess Orion's handling characteristics. The demonstration will provide performance data and operational experience that cannot be readily gained on the ground in preparation for critical rendezvous, proximity operations, docking, as well as undocking operations on beginning on Artemis III.

MARS

Thanks to nearly 20 years of continuous human habitation on the ISS, future Mars-class life support systems can be designed with a 36% reduction in mass.

Mars systems will require less maintenance and fewer spares, making them much safer than current operational systems. These improved life support and environmental control technologies demonstrated on ISS have already been incorporated in Orion and will be put to the test on Artemis II.

Following the proximity operations demonstration, the crew will turn control back to mission controllers and spend the remainder of the day-long orbit verifying system performance in the space environment. In HEO, the crew will assess the performance of the life support systems necessary to generate breathable air and remove metabolically produced water vapor and carbon dioxide. They will remove the Orion Crew Survival System suit they wear for launch and spend the remainder of the in-space mission in plain clothes until they don their suits again to prepare for entry into Earth's atmosphere and recovery from the ocean. A change between the suit mode and cabin mode in the life support system as well as performance of the system during exercise periods where the crew's metabolic rate is the highest and sleep period where the crew's metabolic rate is the lowest, will confirm the life support system's readiness for the lunar flyby portion of the mission.

While still in HEO, Orion will fly beyond the Global Positioning System (GPS) navigation system satellites and the Tracking Data Relay Satellite System (TDRS) communication satellites of NASA's Space Network and allow an early checkout of Deep Space Network (DSN) communication and navigation capabilities. Once Orion travels out to and around the Moon, it will need the Deep Space Network to enable mission control to maintain communication with the astronauts and command the spacecraft, as well as update the navigation system, so this early checkout will confirm readiness to perform the lunar flyby. Once back in range of GPS and TDRS on the return back towards Earth in HEO, Orion will switch back to GPS navigation and TDRS communication just as it will on landing day.

TECHNOLOGY

NASA is developing and implementing key communication and navigation technologies to support robust exploration at and near the Moon. These technologies include the use of GPS signals by spacecraft and lunar surface systems for navigation, optical communications technology to allow multi-gigabit data connections back to the Earth, and expanding the Internet architecture into space through Disruption Tolerant Networking (DTN) standards and software.

After completing checkout procedures in HEO, Orion will perform the translunar injection maneuver, or TLI. With the ICPS having done most of the work to put Orion into HEO, Orion's service module now provides the last push needed to put the spacecraft on a path toward the Moon with a lunar free-return trajectory. The TLI will send the crew on an outbound trip of about four days and around the far side of the moon where they will ultimately create a figure eight extending more than 230,000 miles from Earth as Orion returns on another four day journey back home. This fuel-efficient trajectory harnesses the relationship of the Earth-Moon gravity field, ensuring that—after its trip around the far side of the Moon—Orion will be pulled back naturally by Earth's gravity, with no propulsive moves required.

The Artemis II crew will travel 4,600 miles (7,400 km) beyond the far side of the Moon. From this vantage point, they will be able to see the Earth and the Moon from Orion's windows, with the Moon close in the foreground and the Earth about a quarter-million miles in the background.

The only sunsets they will see during this mission will be in their first lap around Earth on their first day and a brief eclipse of the Sun as the Moon passes between them. The persistent sunlight will provide power production for Orion's solar arrays, but the crew will have to dim lights and shade the windows inside the capsule to simulate nighttime to achieve proper circadian rhythm. To demonstrate

capabilities for maintaining physical condition while flying, the astronauts will have an exercise regimen of aerobic and strength training. These workout plans will leverage decades of human spaceflight experience obtained in low-Earth orbit aboard the International Space Station, and will produce the highest levels of carbon dioxide and water vapor in the cabin, demanding the life support system to maintain proper cabin atmospheric conditions that will further verify the spacecraft's life support system performance.

Throughout the mission, crew will have limited down-time to contact their families, but they will have one off-duty day to mentally prepare themselves for the return home and talk with their families and friends back on Earth via video chat while viewing the solar system out of Orion's windows.

The day before the crew returns home, they will prepare for Earth entry, descent and landing by pressurizing and testing the crew module propulsion systems and storing loose equipment before descent through Earth's atmosphere. On entry day, they will put on their pressurized spacesuits and strap into their seats before the crew module separates from the European service module.

During reentry, the Orion spacecraft will be traveling at nearly 25,000 mph as it reenters the Earth's atmosphere, which will slow it down to 325 mph. Parachutes will then slow it further to about 20 mph for splashdown, ending a mission that will exceed 620,000 miles (over 1,000,000 km). Recovery forces, already positioned at the target landing zone, will be ready to recover the crew from the Pacific Ocean.

Artemis III

TECHNOLOGY

In early 2021, NASA will launch the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) CubeSat to conduct early verification of the lunar near-rectilinear halo orbit (NRHO). CAPSTONE will enter the orbit, rotating together with the Moon as it orbits Earth. The CubeSat will demonstrate how to enter into and operate in NRHO as well as test a new navigation capability. This information will help validate Gateway operational models.

Artemis III will be the culmination of the rigorous testing and more than two million miles accumulated in space on NASA's deep space transportation systems during Artemis I and II.

Orion and its crew of four will once again travel to the Moon—this time to make history with the first woman and next man to walk on its surface. A rapid return to the Moon requires the agency to minimize the number of systems involved with landing humans on the surface by 2024, so while future lunar landings will use the Gateway as a staging point in lunar orbit for missions to the surface, the agency's procurement for a commercially provided HLS left the door open for proposals that didn't use Gateway on early Artemis missions.

For long-term operations, the Gateway provides a staging point for human and robotic lunar missions. The orbiting outpost will support longer expeditions on the Moon, and potentially multiple trips to the surface during a single Artemis mission. The Gateway-to-surface operational system is also analogous to how a human Mars mission may work—with the ability for crew to remain in orbit and deploy to the surface. It is important to gain operational confidence in this system at the Moon before the first human missions to Mars.

The Human Landing System

NASA has selected Blue Origin of Kent, Washington, Dynetics (a Leidos company) of Huntsville, Alabama, and SpaceX of Hawthorne, California to begin development work for the HLS that will land astronauts on the Moon and then safely return them to lunar orbit before their trip back to Earth during Artemis missions. The early development activities, which NASA anticipates will last approximately 10 months, will culminate in early 2021 with a preliminary design-level review in which NASA will determine which designs are the most mature to achieve the first human return to the Moon on Artemis III.

TECHNOLOGY

In addition to NASA's experience in the Apollo program, the agency has developed and terrestrially flown two lander prototypes in the last decade—Mighty Eagle and Morpheus. Work continues on technology development in the areas of precision landing, cryogenic fluid management & propulsion, intelligent/resilient systems and advanced robotics.

These companies offered three distinct lander and mission designs, offering dissimilar redundancy, driving a broad range of technology development and, ultimately, more sustainability for lunar surface access. All three can dock with Orion or the Gateway to receive crew in lunar orbit, providing NASA with flexibility in mission planning.

The Blue Origin-led Human Landing System team includes Lockheed Martin, Northrop Grumman, and Draper. Their Integrated Lander Vehicle (ILV) is a three-stage lander with Blue Origin building the descent element, Lockheed Martin building the ascent element that includes the crew cabin, and Northrop Grumman building the transfer element. Draper will provide the guidance, navigation and control, avionics, and software systems. The ILV will launch on Blue Origin's New Glenn rocket and United Launch Alliance's (ULA) Vulcan heavy-lift rocket

The Dynetics Human Landing System concept includes a single element providing the ascent and descent capabilities, with multiple modular propellant vehicles (MPVs) prepositioned to fuel the engines at different points in the mission. Dynetics plans to launch its lander and MPVs on ULA Vulcan heavy-lift rockets.

The SpaceX Starship is a fully reusable launch and landing system designed for travel to the Moon, Mars, and other destinations. It launches aboard a SpaceX Super Heavy rocket and is fueled in low-Earth orbit before embarking to lunar orbit.

Although the landers will be developed by the commercial companies, NASA teams will be embedded with each company to provide insight and expertise. For the remainder of 2020, NASA will work with the contractors in a "base period" to streamline development of their respective systems to achieve the highest likelihood of getting to the Moon in 2024. The blended government-contractor teams will couple the speed and innovation of the private sector with government experience and expertise to collaborate on products and design approaches to streamline contract deliverables. In early 2021, NASA expects to determine which commercial concepts are the most mature to land astronauts on the Moon for the early Artemis surface expeditions.

The first crew landings will be considered demonstrations of the contractor HLS systems. Similar to the precursor demonstrations for commercial cargo and commercial crew delivery services to the International Space Station, NASA believes that successful demonstrations are an effective approach to validating commercial space transportation capabilities before entering into services contracts.

The agency is planning crewed exploration missions to the lunar surface beginning in 2024 that will include demonstrations of the new HLS systems. The initial missions represent a human return to the Moon for the first time since 1972, but with several key differences, including the use of 21st century technologies and access to more parts of the Moon. Later sustainable surface exploration demonstration missions will make full use of the Gateway-enabled capabilities, including refueling and reuse of all or parts of the lander and conducting critical Mars mission simulations. This approach allows NASA and industry to combine their respective expertise and capabilities into tightly collaborative partnerships needed to meet this challenge before achieving a regular cadence of landings using commercial services contracts later in the decade.

The HLS Program office will oversee all HLS verification, validation and certification to ensure requirements for flight readiness to meet NASA's expectations for crew safety and human rating standards. NASA also will work closely with all HLS contractors to ensure that flight tests are conducted in a relevant environment to reduce as many risks as possible before crewed missions. The HLS Program office will use the best of NASA to ensure the agency's objectives are safely met.

Artemis III Surface Operations

Artist's rendering of astronauts conducting science and exploration activities on the lunar surface.

The exact landing site for Artemis III astronauts depends on several factors, including the specific science objectives and the launch date. High-resolution data received from NASA's Lunar Reconnaissance Orbiter (LRO) has provided incredible views and detailed mapping of the lunar

surface, including changes in lighting throughout the year. The agency is working with the global science community to study different regions that provide key desired traits: access to significant sunlight, which provides minimal temperature variations and potentially the only power source; continuous line-of-sight to Earth for mission support communications; mild grading and surface debris for safe landing and walking or roving mobility; and close proximity to permanently shadowed regions, some of which are believed to contain resources such as water ice.

Through the CLPS initiative, NASA will gain even more surface data through science investigations that will help identify additional areas of interest for human exploration. For instance, investigation results from VIPER, the robotic scout, may also offer valuable information for landing site decisions.

In addition to two crew, the HLS will carry up to 220 lbs (100 kg) of science tools and equipment to the surface, with the goal of returning up to 87.5 lbs (35 kg) of samples. Pending an earlier test of the lander's descent stage, more supplies may be placed on the surface prior to crew arrival. In addition, our CLPS providers may be used to deliver pre-emplaced science instruments and equipment for use by our first human return crew while exploring on the lunar surface.

On this intrepid first week-long expedition, the crew will characterize and document the regional geology, including small permanently shadowed regions, if available. They will collect a variety of samples to return to Earth for later research: rock samples to help date the sequence of impact events on the Moon; core tube samples to capture ancient solar wind trapped in regolith layers; and paired samples of material within and outside a permanently shadowed region to characterize the presence of volatiles and assess geotechnical differences between materials inside and outside of permanent shadows.

While on the surface, crew will live in the cabin of the ascent vehicle—the upper part of the landing system that they will use to get back to lunar orbit when the surface expedition concludes. NASA requires a minimum of two moonwalks during the Artemis III surface expedition, and is currently working to drive down HLS vehicle mass to allocate more resources to spacesuit life support systems. The goal, if mass allows, is for the crew to conduct four planned EVAs, and reserve additional consumables for one unplanned contingency EVA. In this scenario, days 1, 2, 4, and 5 will be primarily focused on moonwalks to conduct science and technology demonstrations, with the latter part of day 5 dedicated to site cleanup. The cleanup may involve securing tools or other moonwalk instruments for use on future expeditions, and will require placement far enough from the lander that they don't cause a hazard during liftoff. Day 3 will be for crew rest, conducting science inside the ascent vehicle, and public engagement activities.

SCIENCE

Artemis science goals will be driven by U.S. and international science community priorities. Broad lunar-based science themes that can be addressed with human-robotic investigations on the Moon include:

- The study of planetary processes
- The study of lunar volatile cycles and the in-situ resource utilization (ISRU) potential of resources for lunar exploration and beyond
- The impact history of the Earth-Moon system
- A platform to study the universe and geospace, including Earth
- Record of the ancient Sun
- A platform for experimental science in the lunar environment

See Appendix 1 for more on the Artemis Science Strategy.

Moonwalks will begin with cabin and suit hardware preparation once the crew has depressurized the lander. Outside on the Moon, the two crew members will spend about 1.5 hours on set-up tasks including configuring the lander for contingency return, and unpacking tools and equipment for the objectives of the day. They also will pre-position dust cleaning equipment to minimize the amount of lunar soil that gets tracked back into the cabin. The crew will spend approximately four hours outside, conducting dedicated science and technology demonstration activities. The scope of exploration will be constrained by the ability to return to the lander should a failure occur. If the LTV can be delivered to the landing site region before the crew arrives, the distance they cover on each moonwalk will greatly expand.

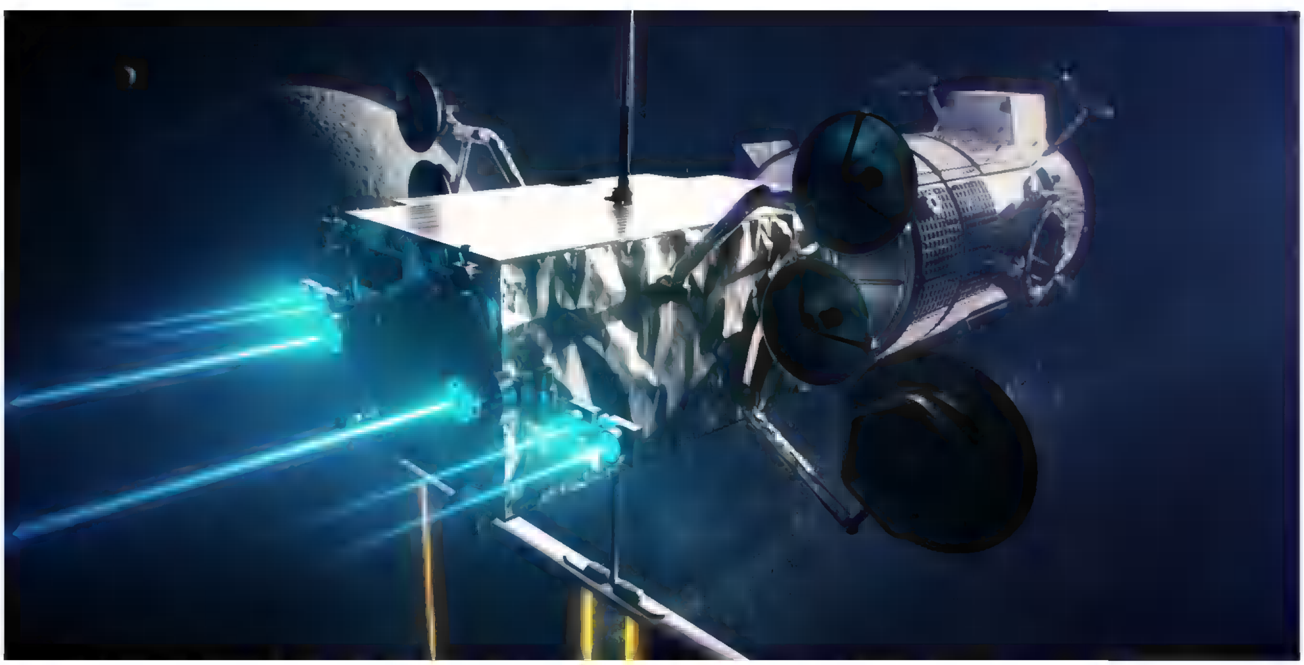
After completing this historic expedition on the lunar surface, the crew will launch from the surface to rendezvous with Orion and their crewmates in lunar orbit. With their pristinely preserved samples from the Moon, the crew will prepare for the three-day trip back to Earth.

When Artemis III lands the first woman and next man on the Moon in 2024, America will demonstrate a new level of global space leadership. With lunar exploration capability re-established, NASA and the world will be ready to build a sustained presence on the lunar surface in preparation for human exploration of Mars.

The Gateway

The first two Gateway modules, the PPE and the HALO, will be integrated on the ground and launched together on a single rocket in 2023.

Maxar Technologies of Westminster, Colorado, is developing the PPE, leveraging heritage systems from the company's geostationary orbit satellites. The spacecraft's solar electric propulsion system is



Artist's rendering of the Power and Propulsion Element and the Habitation and Logistics Outpost (HALO) in lunar orbit.

three times more powerful than current systems, and provides Gateway with electrical power, control, thrust, and communication capabilities. The PPE also provides accommodations for science and technology demonstration payloads.

Northrop Grumman of Falls Church, Virginia, is developing the HALO, which will be the initial crew cabin for astronauts visiting the Gateway. Its primary purpose is to provide basic life support needs for the visiting astronauts after they arrive in the Orion and prepare for their trip to the lunar surface. It will provide command, control, and data handling capabilities; energy storage and power distribution; thermal control; communications and tracking capabilities; as well as environmental control and life support systems to augment the Orion spacecraft and support crew members. It also will have several docking ports for visiting vehicles and future modules, as well as space for science and stowage.

Cargo deliveries, initially provided by SpaceX of Hawthorne, California, will service the Gateway with pressurized and unpressurized cargo, including food and water for crew, science instruments, and supplies for the Gateway and lunar surface expeditions.

Once in lunar orbit, the Gateway will enter a period of scientific operations. Designed to operate autonomously and with internationally agreed-upon interoperability standards, it will provide a unique platform to conduct science investigations in deep space and outside the protection of the Earth's Van Allen radiation belts. The international science community has identified heliophysics, radiation, and space weather as high-priority investigations to fly on the Gateway. The first two payloads are a radiation instrument package provided by ESA and a space weather instrument suite provided by NASA.

ESA's radiation investigation, the European Radiation Sensors Array (ERSA) will help provide an understanding of how to keep astronauts safe by monitoring the radiation exposure in Gateway's unique orbit. The NASA space weather instrument suite, Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES), will monitor solar particles and solar wind. These early instruments will improve our deep space environmental forecasting capabilities to better protect our human deep space explorers and human health and performance investigations building off of our decades-long research in low-Earth orbit. The data gathered by these payloads, coupled with Gateway operational experience, will be leveraged to enable sustainable lunar operations and successfully complete the first crewed mission to Mars.

Chapter 3: Extending Lunar Missions and Preparing for Mars

After Artemis III, NASA and its partners will embark on missions on and around the Moon that also will help prepare us for the types of mission durations and operations that we will experience on human missions to Mars. In this drive toward a more robust human lunar enterprise, NASA, U.S. industry, and our global partners will establish the infrastructure, systems, and robotic missions that can enable a sustained lunar surface presence. To do this, we will expand the Gateway's capabilities, gain high confidence in commercial lunar landers departing from the Gateway, and establish the Artemis Base Camp at the South Pole of the Moon.

With the core Artemis elements in operation—SLS, Orion, HLS, the Gateway, and potentially the LTV—NASA is engaging international and commercial partners to pursue additional surface capabilities. With this approach, NASA will leverage years of investment in the systems needed to return to the Moon, while fostering new partnerships and spurring new capabilities to ensure that humanity's return to the Moon is sustainable and extensible to the first human mission to Mars. One such example is an extensible and scalable lunar communications and navigation architecture, known as LunaNet.

With a LunaNet architecture in place, robotic landers, rovers, and astronauts on the Moon will have network access similar to networks on Earth. Rovers analyzing samples can send their data to relays orbiting the Moon, which can then transmit that data back to Earth. Astronauts on the lunar surface will be able to receive real-time alerts generated from space weather instruments of incoming solar flares, giving them ample time to seek cover. Each communications link will be a connection to the larger network, allowing data transfers between any assets on the network. LunaNet will also support positioning, navigation and timing (PNT) services and allow for more precise surface operations and science than ever before.

This flexible solution to enable exploration and science activities can be provided by a combination of NASA, commercial partners, international partners, and others. This flexibility will be critical as NASA moves forward with its plans for both lunar and solar system exploration, allowing LunaNet to grow in a manner analogous to the development of the internet on Earth.

Numerous potential international partners have expressed their interest in lunar surface operations. International partners could provide key contributions such as rovers, surface habitats, and ISRU-related equipment. Moreover, activities conducted on the surface of the Moon and in cislunar space generally represent an excellent opportunity for NASA to expand its global partnerships, with a focus on new, emerging space agencies.

On the Surface: Artemis Base Camp

Artist's concept of the Artemis Base Camp.

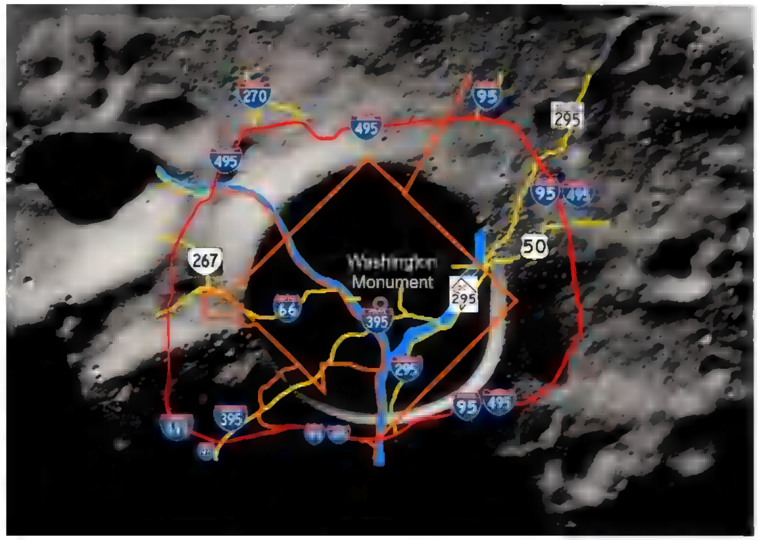
Artemis Base Camp will be our first foothold on the lunar frontier. The three proposed primary mission elements of Artemis Base Camp are the Lunar Terrain Vehicle (unpressurized rover) to transport suited astronauts around the site; the habitable mobility platform (pressurized rover) that can enable long-duration trips away from Artemis Base Camp; and the foundation surface habitat that will accommodate four crew on the lunar surface and anchoring Artemis Base Camp and the U.S. presence at the South Pole. Together—along with supporting infrastructure such as communications, power, radiation shielding, and waste disposal and storage planning—these elements comprise a sustained capability on the Moon that can be revisited and built upon over the coming decades while also testing systems that will be required for human missions farther into the solar system.

The additional infrastructure at the base camp will support one- to two-month expeditions on the surface to learn more about the Moon and the universe at large, and to develop new technologies that will advance our national industries while developing new resources that will help grow a new lunar economy. The Artemis Base Camp will demonstrate America's continued leadership in space and prepare us to undertake humanity's first mission to Mars.

Mobility is vital to the long-term exploration and development of the Moon. In addition to its size, the Moon's geography is complex and its resources dispersed. Evaluating potential sites for Artemis Base Camp, such as near Shackleton Crater, reflects the immense scale of the lunar geography. Robust mobility systems will be needed to explore and develop the Moon and to explore Mars. The habitable

mobility platform is a particularly important mission element as the first mission to Mars will use a similar type of spacecraft.

See *Appendix 6: NASA's Plan for Sustained Lunar Exploration Development* for more on the Artemis Base Camp and other elements of sustainable lunar exploration.



This image of Shackleton Crater on the lunar South Pole was captured by the Lunar Reconnaissance Orbiter. Laid on top is the 64-mile long Washington, D.C. Capital Beltway for scale.

Lunar Resources

As our sustained presence grows at the Moon, opportunities to harvest lunar resources could lead to safer, more efficient operations with less dependence on supplies delivered from Earth. NASA has several current ISRU investments through partnerships with industry and academia. Prospecting, extraction and mining initiatives are advancing our capabilities to find and harness resources from the lunar regolith. Chemical and thermal process developments may provide options to break down naturally occurring minerals and compounds found on the Moon and convert them to human consumables or even propellant. Other potential longer-term applications could lead to extraterrestrial metal processing and construction of habitats or other lunar surface structures using resources found on the Moon. Many of these technologies could be demonstrated and advanced on the Moon for future use at Mars. And while the Moon has no atmosphere, we know that the Mars atmosphere is rich in carbon dioxide, so NASA is also investing in initiatives to focus on atmospheric extraction and conversion of CO2 to other useful elements or compounds.

TECHNOLOGY

Astronauts at Artemis Base Camp will test a wide set of new technologies in six priority areas encompassed by NASA's Lunar Surface Innovation Initiative.

For example, advancing ISRU technologies could lead to future production of fuel, water, and/or oxygen from local materials, decreasing supply needs from Earth. Advanced solar and fission power systems and autonomous manufacturing technologies could also be demonstrated at the Artemis Base Camp for long-duration operations on the Moon and Mars.

See Appendix 2 for more on the Artemis Lunar Surface Technology Strategy.

In April 2020, the White House issued an Executive Order, "Encouraging International Support for the Recovery and Use of Space Resources," addressing U.S. policy regarding the recovery and use of resources from the Moon and other celestial bodies. This Executive Order directs the Secretary of State to lead a U.S. Government effort to develop joint statements, bilateral agreements, and multilateral instruments with like-minded foreign states to enable safe and sustainable operations for the commercial recovery and use of space resources. NASA is supporting State Department efforts to advance the Executive Order by conducting a trailblazing purchase of an extraterrestrial resource. Specifically, NASA plans to purchase from one or more

providers a sample of an extracted lunar resource for a nominal dollar value. The sample will be delivered in place on the lunar surface for retrieval by NASA at a later date. This process will establish a critical precedent that lunar resources can be extracted and purchased from the private sector in compliance with Article II and other provisions of the Outer Space Treaty.

In Orbit: The Gateway

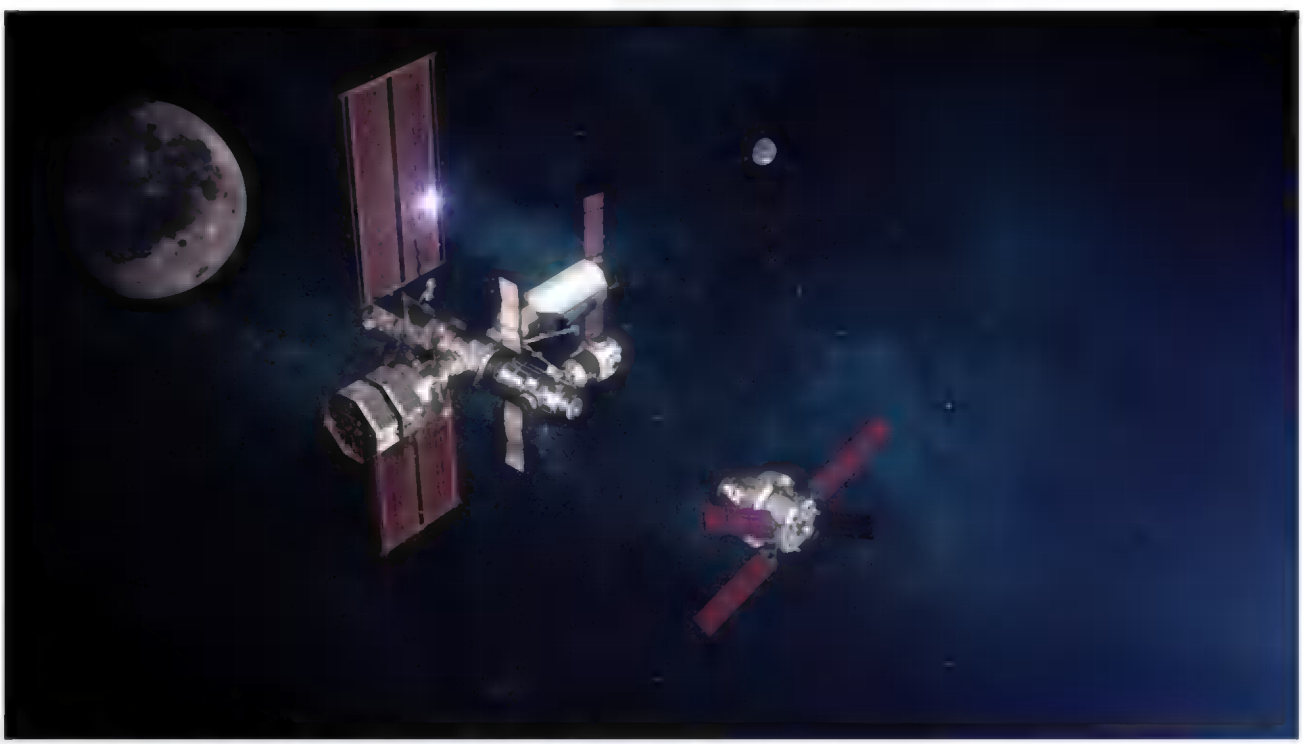
The Gateway will forge U.S. leadership and establish a presence in the region between the Moon and Earth with our international partners. The orbiting outpost also will offer a unique platform from which to conduct science investigations, with the potential to navigate to different orbits around the Moon.

MARS

The Gateway's capabilities could help NASA and its partners prepare for human missions to Mars by enabling Mars mission simulations (or analogs) while the crew is still relatively close to home.

While the Mars architecture is not finalized, the Gateway is our technical and operational proving ground for that type of Mars mission.

While the Gateway is a much smaller and more focused platform than the International Space Station, NASA is taking the lessons learned from that experience to implement a lunar architecture in which multiple providers (of crew systems, propulsion, logistics, science platforms, technology demonstrators, etc.) can provide complementary capabilities that increase the overall success and resiliency of the lunar architecture. Early work to define a series of International Deep Space Interoperability Standards has formed the basis through which industry and international partners can "plug and play" into the deep space exploration architecture. NASA and the international community collaborated to define the standards with the goal of defining interfaces and environments to facilitate cooperative deep space exploration endeavors. These standards focus on



Artist's concept of the Gateway including international contributions, with Orion approaching.

topics prioritized in this early phase of exploration planning and are not intended to dictate design features beyond the interfaces. The standards include: avionics, communication, environmental control and life support systems, power, rendezvous, robotics, thermal control, and software.

Our current space station partners will provide important contributions to Gateway, comprising advanced external robotics, additional habitation, and possibly other enhancements. Canada announced in February 2019 that it intends to participate in the Gateway and contribute advanced external robotics. In October 2019, Japan announced plans to join the United States on the Gateway with contributions of habitation components and logistics resupply. In November 2019, ESA received authorization and funding to support its planned contributions to the Gateway including habitation and refueling. Russia has also expressed interest in cooperating on the Gateway.

The Gateway also will play a pivotal role in Mars mission simulations at the Moon. For these simulations, we currently envision a four-person crew traveling to the Gateway and living aboard the outpost for a multi-month stay to simulate the outbound trip to Mars, followed by two crew traveling down to Artemis Base Camp and exploring the lunar surface with the habitable mobility platform, while the two remaining crewmembers stay aboard the Gateway. The four crew are then reunited at the Gateway for another multi-month stay, simulating the return trip to Earth, before landing back home.

These missions will be by far the longest human deep space missions in history. They will be the operational tests of our technical and operational readiness for the first human Mars mission.

Summary

All major components required to lead a robust human return to the Moon are underway, with U.S. commercial lunar robotic deliveries leading the way in 2021. NASA's deep space transportation systems are in the final stages of testing before integration. The Artemis I and Artemis II flight tests will validate rocket and spacecraft performance and set America on a course to once again return astronauts to the Moon. NASA will also work with commercial partners to build landers and conduct risk-reducing tests in the lead-up to the landings on the Artemis III mission and beyond.

Our charge is bold and to meet it, we must employ innovative development approaches. At every milestone we will learn and improve our technical methods. Our top priority is the safety of our people—not just the astronauts who we send on these missions, but also the thousands of workers on the ground who make it all possible.

With the approach laid out in this document, NASA will leverage years of hard work and national investment in the systems needed to return to the Moon, while enabling current and new partners and capabilities to achieve sustainability—all of which will lead to the first human mission to Mars.

This vision, coupled with support from key stakeholders and one of the strongest budgets in NASA's history, is the way forward to the Moon. With modern deep space systems in development, a growing corps of astronauts, and new science investigations and technologies planned to study the

Moon ahead of a human return, we are closer to landing crew on the Moon again than at any other time in our history since the Apollo program. The sooner we go to the Moon, the sooner we send astronauts to Mars.

APPENDIX 1:
Artemis Science Strategy

Priorities & Principles

- Achieve the decadal survey objectives across the disciplines that can be addressed at the Moon or near the Moon
- Perform all research to the standards of NASA Science, including competitive selections, open data policies, etc.
- Enable competitive research through Mission of Opportunities or otherwise on or around the Moon

Science Goals

The Moon is a cornerstone for Solar System science. The Artemis science goals will be driven by the U.S. and international science communities' priorities. The scientific opportunities represented by the Moon, as a research platform or focus, have been captured in a multitude of community input documents. It is important to stress that Artemis enables science in a plethora of disciplines not just lunar and planetary science. Broad lunar-based science themes that can be addressed include:

- Understanding planetary processes
- Understanding volatile cycles
- Interpreting the impact history of the Earth-Moon system
- Revealing the record of the ancient sun
- Observing the universe from a unique location
- Conducting experimental science in the lunar environment
- Investigating and mitigating exploration risks to humans

Implementation Strategy

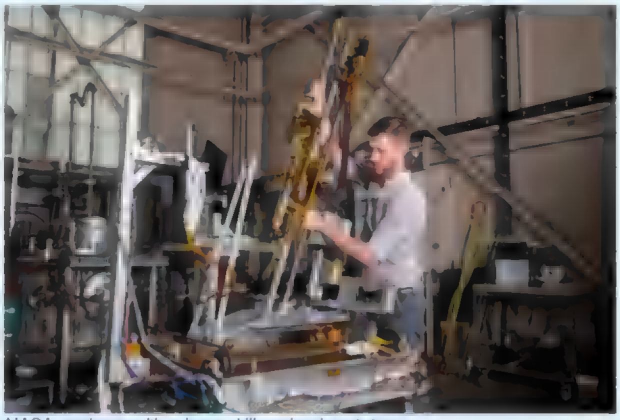
A coordinated effort among NASA's mission directorates is underway to ensure that these scientific priorities are met. This implementation strategy includes:

- Develop a pipeline of science and technology payloads to be delivered to the lunar surface by commercial companies
- Develop mobility systems to expand and enhance science investigations on the lunar surface
- Leverage International Partnerships for additional opportunities (e.g., instruments, rovers)
- Obtain new scientific data from lunar orbit pertinent to planetary, solar system, and cosmological observations using SmallSats
- Use of new human exploration systems, such as Gateway and the Human Landing System, to enable science
- Lead the science mission planning for Artemis crews on the lunar surface including developing the capabilities they will need to conduct effective scientific exploration. These capabilities relate to
    - Field geology
    - Sample collection and return
    - Instrumentation for surface and near-surface environment characterization (e.g. electromagnetic interference, charged particle, neutral particulates)
    - Access to cold regions
    - Access to lunar far side
- Create a pathway for component/sensor/technology development that enables science (e.g., TRL enhancement)

APPENDIX 2: Artemis Lunar Surface Technology Strategy

Image credit: Ball Aerospace

Establishing a sustainable human presence on the Moon allows NASA to develop and test new approaches, technologies, and systems that will enable us to function in other, more challenging environments. Technology investments for Artemis are being targeted at technologies that would vastly reduce the cost of deep space exploration, making possible even more ambitious missions to Mars. By working side by side with commercial enterprises and international partners, combining knowledge and expertise to fully explore the lunar surface, many technical advances and breakthroughs will be made that will feed technological and economic growth on Earth.


NASA engineer with a lunar drill payload prototype.

Technology Goals

The Lunar Surface Innovation Initiative (LSII) activities are implemented through a combination of in-house activities, competitive programs, and public-private partnerships aimed to spur the creation of novel technologies needed for lunar surface exploration and accelerate the technology readiness of crucial systems and components.

Priorities

Through LSII, NASA's Space Technology Mission Directorate (STMD) is developing and demonstrating capabilities to retire technology hurdles in the following areas:

- In-situ resource utilization technologies for collecting, processing, storing, and using material found or manufactured on the Moon or other planetary bodies.
- Surface power technologies that provide the capability for sustainable, continuous power throughout the lunar day and night.
- Dust mitigation technologies that diminish dust hazards on lunar surface systems such as cameras, solar panels, spacesuits, and instrumentation.
- Extreme environment technologies that enable systems to operate throughout the range of lunar surface temperatures.
- Extreme access technologies that enable humans or robots to efficiently access, navigate, and explore previously inaccessible lunar surface or subsurface areas.
- Excavation and construction technologies that enable affordable, autonomous manufacturing or construction.

Implementation Strategy

- Ensure that there is an ambitious, cohesive, executable agency strategy for developing and deploying the technologies required for successful lunar surface exploration.
- Integrate a broad spectrum of stakeholders to develop an acquisition strategy that efficiently facilitates robust collaborations and partnerships with industry and academia.
- Address planning, implementation, and budget needs to enable lunar surface activities across STMD programs.
- Collaborate with agency stakeholders, other government agencies, universities, industry, and international partners to better align the agency's investments relative to lunar surface demonstrations.

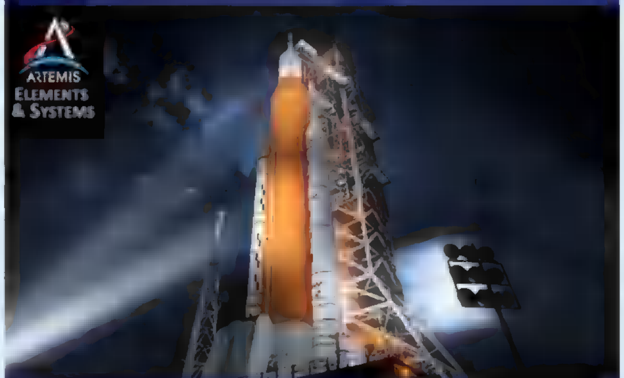
A key tenet of LSII is the Lunar Surface Innovation Consortium, a collaboration across industry, academia, and government to successfully develop the transformative capabilities for lunar surface exploration. The consortium assists NASA in:

- Identifying lunar surface technology needs and assessing the readiness of relative systems and components.
- Making recommendations for a development and deployment strategy of the technologies required for successful lunar surface exploration.
- Providing a central resource for gathering information, integrating technology interfaces, and sharing results.

APPENDIX 3: Core Mission Elements

The following cards represent the primary components under development or in early formulation for Artemis missions at the Moon. These are considered a snapshot and not fully representative of every system required for human-robotic lunar exploration.

SPACE LAUNCH SYSTEM BLOCK 1

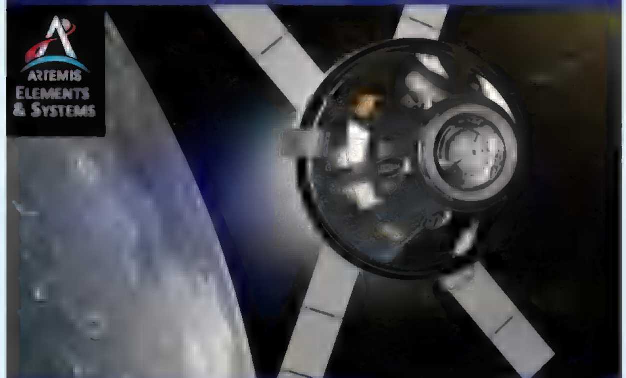


Key Components and Functions

- High payload mass and volume capability
- Ability to send Orion, crew, and cargo to the lunar vicinity on a single mission

The Space Launch System (SLS) is a powerful, advanced rocket for a new era of human exploration beyond Earth's orbit. SLS will launch astronauts aboard the Orion spacecraft. SLS is designed to safely send humans to deep space and can support a variety of complex missions.

ORION CREW VEHICLE



Key Components and Functions

- Habitable & stowage volume
- ECLSS
- Crew quarters
- Independent Guidance, Navigation, and Control (GN&C)
- Independent communication system
- Independent power generation
- Independent thermal control

The Orion spacecraft is designed to be launched on the Space Launch System (SLS) and is capable of carrying and sustaining a crew of four for 21 days (with on-board consumables) or longer (when docked to a habitation system that allows Orion systems to be powered down).

EXPLORATION GROUND SYSTEMS

Key Components and Functions

- SLS Launch Pad 39B
- Crawler-transporter
- Vehicle Assembly Building
- Mobile Launcher
- Landing pads
- Landing runway

EGS was established to develop and operate the systems and facilities necessary to process and launch government and commercial rockets and spacecraft during assembly, transport, and launch and return of rocket stages or return of winged spacecraft to landing sites.

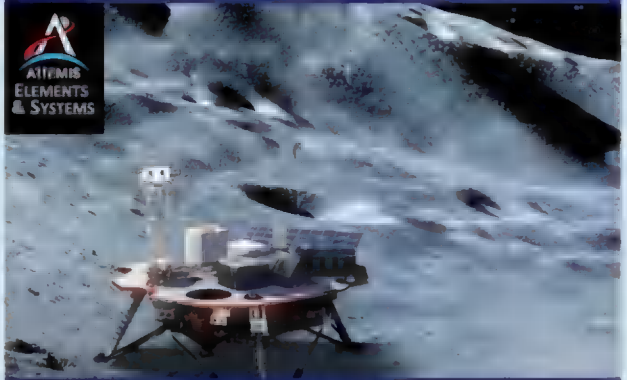
DEEP SPACE NETWORK

Key Components and Functions

- Upgraded to provide 100 Mbps downlink, 20 Mbps uplink
- 2 antennas upgraded at each DSN complex: Goldstone, Canberra, and Madrid
- Services compatible with international partner ground stations

Upgrades to the Deep Space Network's (DSN) 34-meter subnet will provide continuous high-rate command and telemetry services to the Gateway, Human Landing System, and other Artemis space systems. These new services are required to support human operations at the Moon and to return high volumes of scientific data from payloads planned for the Gateway and the Lunar surface. The Deep Space Network upgrades are critical to meeting the nation's challenge to land humans on the Moon by 2024 and following human exploration of Mars.

COMMERCIAL LUNAR PAYLOAD SERVICES



Key Components and Functions

- End-to-end payload delivery services
- Small to medium payloads, initially up to ~500 kg
- Delivery of science instruments and technology demonstration payloads on and at the Moon

The Commercial Lunar Payload Services (CLPS) provides commercial delivery services for small and medium payloads to the lunar surface. By engaging American companies to deliver key science and technology payloads, CLPS is crucial to NASA's strategic goal of catalyzing lunar economic growth. CLPS is leading America's return to the lunar surface and is an important predecessor to the eventual return of humans to the lunar surface in 2024.

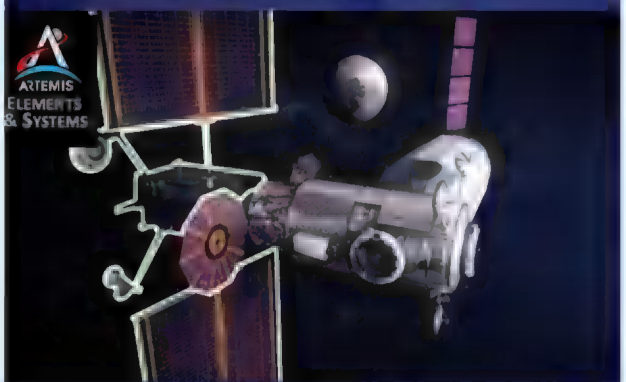
VOLATILES INVESTIGATING POLAR EXPLORATION ROVER

Key Components and Functions

- Carries the Neutron Spectrometer System (NSS), Near-Infrared Volatiles Spectrometer System (NRVSS), Mass Spectrometer Observing Lunar Operations (MSolo), and the TRIDENT drill
- Driving distance of 10s of km
- Survives the lunar night for 100-day mission duration

Planned for delivery to the lunar surface in 2023 and about the size of a golf cart, the Volatiles Investigating Polar Exploration Rover (VIPER) will roam several miles, using its four science instruments —including a 1-meter drill—to sample various soil environments. VIPER will collect about 100 days of data that will be used to inform the first global water resource maps of the Moon.

POWER AND PROPULSION ELEMENT

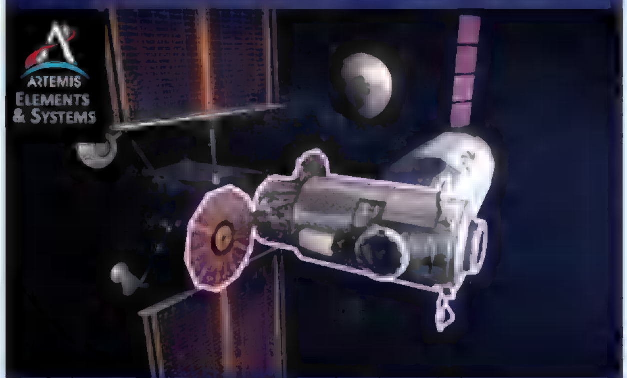


Key Components and Functions

- High-gain communications with Earth, space-element to space-element communication, and lunar surface relay
- Command and control capability
- Provides translation delta velocity (ΔV) with 12.5 kW electric propulsion
- Maintains attitude via non-propulsive (e.g., momentum wheels) and propulsive (e.g., thrusters) control
- Generates 60 kW+ power
- Transfers power to the Gateway elements
- Thermal control
- Accommodations for science and technology demonstration payloads

The Power and Propulsion Element (PPE) will be integrated with the HALO and launched to lunar Near Rectilinear Halo Orbit.

HABITATION AND LOGISTICS OUTPOST



Key Components and Functions

- Habitable and stowage volume
- ECLSS pressure control system, inter-modular ventilation
- Distributed Integrated Modular Avionics (DIMA) architecture
- Power pass-through for other Gateway elements
- Thermal control
- Provide communications with visiting vehicle and lunar surface
- Support external robotics & payloads via LPGFs and SORIs

The Habitation and Logistics Outpost (HALO) will be integrated with the PPE and launched on a commercial vehicle to the Near Rectilinear Halo Orbit. The HALO provides radial and axial IDSS compatible docking ports for visiting vehicles.

DEEP SPACE LOGISTICS

Key Components and Functions

- Independent guidance, navigation, and control
- Independent communication system
- Independent power generation and thermal control
- Cargo resupply and trash disposal
- Up to 5,000 kg of pressurized payload/cargo mass
- From 1,000 to 2,600 kg of unpressurized payload/cargo mass
- Stowage volume

Gateway Logistics Services deliver cargo, science experiments, and supplies to the Gateway, such as sample collection materials and other items the crew may need on the Gateway and during their expeditions on the lunar surface. They also provide stowage volume while attached to Gateway and trash disposal upon departure.

EXPLORATION EXTRAVEHICULAR ACTIVITY SYSTEM

Key Components and Functions

- High mobility pressure garment
- Portable Life Support System with motherboard-style packaging
- Integrated communications and informatics systems
- Common system servicing and geology tools
- Vehicle interface systems and equipment

The destination-agnostic Exploration Extravehicular Activity System (xEVA) is built for both Moonwalks and spacewalks and is designed for upgrades as technologies advance and missions evolve. The vehicle interface systems and equipment feature a common design but can be customized to fit into multiple elements of the Artemis campaign. xEVA is designed for a long service life and leverages systems from ISS testing for most planned servicing tasks.

HUMAN LANDING SYSTEM

Key Components and Functions

- Habitable volume
- Power generation
- Energy storage
- Propulsion (chemical)
- Thermal control
- Avionics
- Communications
- GN&C
- ECLSS, tanks and consumables
- EVA equipment/ accommodations

The Human Landing System will be the final vehicle that the crew board for the descent to the lunar surface. After surface expeditions, the crew will return to the HLS for ascent back to lunar orbit before the return trip home to Earth. Early HLS are expected to provide surface access for two crew, with later, more sustainable HLS accommodating four crew on the surface.

LUNAR TERRAIN VEHICLE

Key Components and Functions

- Limited power generation
- Energy storage
- Avionics
- Communications
- EVA / crew accommodations (2 crew)
- Payload stowage volume
- Tele-operated science accommodations

The Lunar Terrain Vehicle (LTV) is the surface transportation system for the 2024 human lunar return. Significantly extends the range of crew excursions, enabling more science, resource prospecting, and exploration. The LTV also can be tele-operated to perform science during the non-crewed lunar periods and transport small deployable assets to desirable locations.

LUNAR GROUND STATIONS

Key Components and Functions

- Global network of 18-meter class antennas
- Services compatible with DSN's 34-meter subnet
- Additional capacity for Artemis systems
- Potential for commercialization

Lunar Ground Stations (LGS) will create a global network of 18-meter class antennas critical to meeting future demand for communication and tracking services created by sustained Lunar exploration. Additional capacity is required to service Artemis robotic and support elements such as CLPS, LSSMS, GLS, and LunaNet. Migrating traffic from the DSN's 34-meter subnet to the new LGS will preserve DSN capacity for NASA's planetary science missions and human exploration of Mars. NASA will pursue opportunities for commercial entities to provide LGS service.

LUNANET

Key Components and Functions

- Networked communication services
- Lunar PNT services
- Science and alert services
- Architected to accommodate NASA, commercial, and international partner assets
- Inclusive of lunar relay, lunar surface, and Earth assets
- Mars forward architecture

LunaNet is envisioned as a framework of standards, protocols, and interfaces to support a scalable communications and navigation network for NASA and other partners in cis-Lunar space. LunaNet will provide the basis for seamless robotic, science, and human operations by providing networked communication, PNT, science, and alert services. The LunaNet architecture is scalable to meet immediate mission needs at the Lunar south pole and Lunar far side and to provide global Lunar coverage as demand grows.

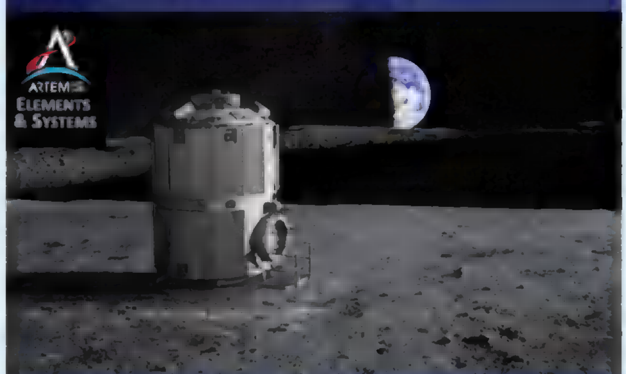
HABITABLE MOBILITY PLATFORM

Key Components and Functions

- Habitable volume
- ECLSS
- Avionics
- Communication
- Power generation and storage
- EVA suit accommodation

The Habitable Mobility Platform (HMP) will vastly expand the range of possible excursions and enable new science, resource prospecting, and exploration. The HMP will be used for analogs of Mars surface activities on the Moon to reduce risk and optimize operations concepts. The lunar HMP will be greatly leveraged for the Mars HMP.

FOUNDATION SURFACE HABITAT



Key Components and Functions

- Habitable and stowage volume
- ECLSS
- Power pass-through for other elements
- Thermal control
- Provide communications with surface elements and Gateway
- Support external robotics & payloads
- EVA suit compatibility or airlock

The Foundation Surface Habitat (FSH) will provide a continuous, long-term outpost for crew to visit for up to 60 days. Delivered through commercial / international partnerships, the FSH will provide the support necessary for extended human occupation.

LUNAR/MARS SURFACE POWER

Key Components and Functions

- Surface architecture depends on power capability delivered with landers
- Power level dependent on propellant type and transfer strategy
- Lunar and Mars commonality assessment desired

To support sustainable operations through the lunar night and empower human exploration of Mars, NASA is developing a modular nuclear fission power source up to 10 kW. Near-term demonstration on the lunar surface can provide reliable power to human landers, habitats, and ISRU systems continuously through eclipse periods and provide a proving ground to extend the capability as a power source that will enable Mars exploration.

LUNAR SURFACE INNOVATION INITIATIVE

Key Components and Functions

- In-situ resource utilization
- Fission surface power
- Extreme access
- Excavation and construction
- Lunar dust mitigation
- Extreme environments

The Lunar Surface Innovation Initiative (LSII) is a technology development portfolio to enable human and robotic exploration on the Moon and future operations on Mars. Through LSII, NASA is developing and performing demonstrations to retire the primary technology hurdles in key capability areas. The activities will be implemented through a combination of unique NASA work and public-private partnerships.

APPENDIX 4: Artemis Flight Readiness

Orion Water Impact Testing

Water impact testing provides high fidelity data of the forces that the Orion spacecraft structure and its astronaut crew would experience, helping to protect the crew and informing future designs. Engineers have conducted 16 drop tests of an Orion test article in the hydro impact basin at the Landing and Impact Research Facility at NASA's Langley Research Center in Hampton, Virginia. They investigated landing technologies, including air bags, retro rockets, shock absorbing struts and crushable structures. In 2011, ascent abort scenarios were performed in six drops during rough seas, and 10 drops with a ground test article using the heat shield from Exploration Flight Test-1 tested atypical landing scenarios. The campaign of swing and vertical drops simulated water landing scenarios to account for different velocities, parachute deployments, entry angles, wave heights and wind conditions the spacecraft may encounter when landing in the ocean.

Orion Heat Shield Testing

The Orion heat shield was redesigned from one piece to individual blocks of material following the Exploration Flight Test-1 in 2014. This new design introduced several unknowns that prompted further testing and risk reduction. Engineers performed more than 30 tests across the United States on the new design to investigate the effects of the block structure that could disrupt the smooth airflow and cause localized heating spots. Understanding both effects is critical to confirm the heat shield will thermally protect the astronauts during reentry. Testing concluded in March 2019 at Langley with a 6-inch Orion heat shield model in the 20-inch Mach 6 wind tunnel. The 6-inch Orion heat shield model was machined to represent small-scale features, including the patterns expected as the heat shield ablates, or slowly burns away as planned, during reentry flight. Orion's heat shield will help it endure the approximately 5,000 degrees Fahrenheit it will experience upon reentry. The heat shield that will protect Orion on Artemis I was installed on the crew module in Aug. 2018.

Orion Parachute Testing

NASA completed the final test of Orion's parachute system in 2018, at the U.S. Army's Yuma Proving Ground in Arizona, to qualify the system for Artemis flights with astronauts. Over the course of eight tests, engineers evaluated the performance of the parachute system, consisting of 11 parachutes, during normal landing sequences as well as several failure scenarios and a variety of potential aerodynamic conditions to ensure astronauts can return safely from deep space missions. The system has a series of cannon-like mortars, pyrotechnic bolt cutters, and more than 30 miles of Kevlar lines attaching the top of the spacecraft to the 36,000 square feet of parachute canopy material. In about 10 minutes of descent through Earth's atmosphere, everything must deploy in precise sequence to slow Orion and its crew from about 300 mph to a relatively gentle 20 mph for splashdown in the ocean.

Orion Crew Module Uprighting System Testing

In March 2019, off the coast of Atlantic Beach, North Carolina, engineers tested the crew module uprighting system (CMUS) to ensure the Orion capsule can be oriented right-side up once it returns from its deep space missions. When Orion splashes down in the ocean, it can settle in one of two positions. The CMUS deploys a series of five, bright orange airbags to flip the capsule right-side up in the event the Orion lands upside down. It takes less than four minutes for the system to upright the capsule to help protect the astronauts inside that are returning home from future deep space missions. Several tests performed with a mockup of the Orion crew capsule demonstrated that even if one of the airbags failed to inflate, the CMUS would still be able to perform as intended. The system was previously tested in the Neutral Buoyancy Lab, a giant pool at NASA's Johnson Space Center in Houston, primarily used for astronaut training, as well as off the coast of Galveston, Texas. Engineers also partnered with the Coast Guard in the Atlantic Ocean to test the CMUS in more challenging waves, similar to those where Orion is expected to land.

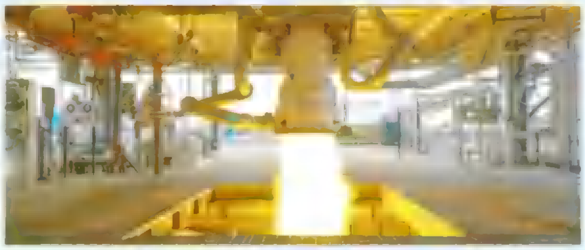
Orion's Launch Abort System Testing

Orion's launch abort system (LAS), designed to carry crew to safety in the event of an emergency during launch or ascent, is being rigorously tested before the first crewed Artemis mission. The LAS consists of three solid rocket motors: the abort motor pulls the crew module away from the launch vehicle; the attitude control motor steers and orients the capsule; then the jettison motor ignites to separate the LAS from Orion prior to parachute deployment and to ensure a safe crew landing. The LAS is managed by Langley and NASA's Marshall Space Flight Center in Huntsville, Alabama. The attitude control motor and jettison motor have each been tested for the third and final time during hot, ambient and cold conditions. The abort motor has been tested twice. The final abort motor test is scheduled for 2022, marking the final test to qualify the LAS for the Artemis II mission with crew. In 2010, Orion's LAS successfully tested the system from the launch pad during a pad abort test at White Sands Missile Range in New Mexico. In July 2019, an ascent abort test at NASA's Kennedy Space Center in Florida successfully demonstrated the system could outrun a speeding rocket and pull astronauts to safety under the greatest aerodynamic forces expected during ascent.

Orion Service Module Structural Testing

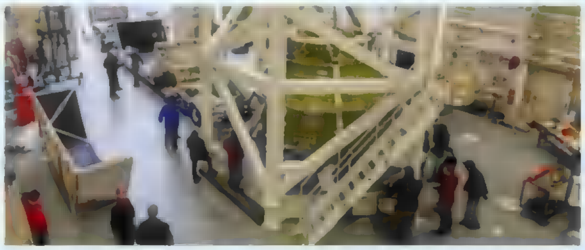
From November 2015 through March 2017, NASA, ESA (European Space Agency) and Airbus, ESA's lead contractor for Orion's European Service Module, completed evaluation of the full-size test version of the service module at the Space Environments Complex at NASA's Plum Brook Station in Sandusky, Ohio. These tests verified the flight readiness and structural integrity of the service module, which will carry air, nitrogen and water for the crew, as well as the spacecraft in-space propulsion and power systems. The first test focused on the successful deployment of the spacecraft's solar array wings. The deployment of the 24-foot wing qualification model confirmed the array unfurled properly and locked into place and that all of the mechanisms functioned as expected. Next, the test article moved into the world's most powerful reverberant acoustic test chamber, where it was blasted with more than 150 decibels and up to 10,000 hertz of sound pressure. The service module was then placed atop a vibration table to simulate launching on the Space Launch System (SLS) rocket. Finally, the spacecraft's fairings and adaptor were subjected to pyro-shock testing to simulate separation scenarios during launch and return to Earth.

Orion Service Module Propulsion Testing



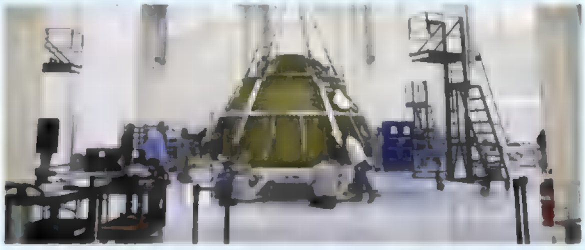
NASA and ESA completed 51 test sequences, conducted in two phases, to certify the European Service Module's propulsion system for Artemis I using the Propulsion Qualification Module at the White Sands Test Facility in Las Cruces, New Mexico. The test article was delivered by ESA and Airbus to White Sands in 2017, to verify the performance of the multiple types of rocket engines (orbital maneuvering system engine, auxiliary thrusters, reaction control system), propellant feed systems, and various other propulsion operations during nominal and off-nominal conditions.

Orion Structural Testing



Lockheed Martin engineers in Denver are conducting a series of tests using Orion's structural test article comprised of three main elements: a crew module, service module and the launch abort system. During the next few months, the test articles will undergo load, acoustic, vibration, shock and lightning tests. The lightning test is nearing completion in spring 2020 and is collecting data to evaluate the indirect effects on an Orion spacecraft if a lightning strike occurred at the pad or during ascent. Final planning and preparations are underway in Denver for a pyro shock test to jettison the solar array fairings. The test will perform an ordnance operation in May 2020 that will jettison the three fairings the cover the service module in a flight scenario.

Orion Pressure Vessel Testing

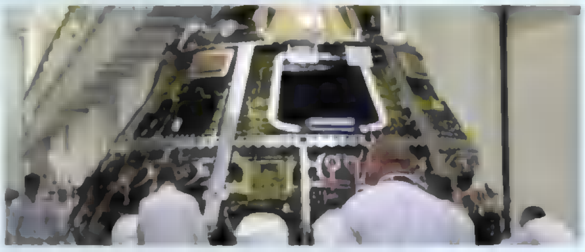


In January 2016, technicians at Michoud Assembly Facility in New Orleans finished welding together the primary structure of the Orion spacecraft destined for deep space and prepared it for delivery to Kennedy in February. In May 2016, engineers at Kennedy conducted a series of tests on the spacecraft's pressure vessel, or underlying structure of the crew module. Strain gauges measured the strength of the welds on the spacecraft as it was pressurized to greater than the maximum pressure it is expected to encounter on orbit.

Orion Power-on Testing

In August 2017, the Orion crew module was powered on at Kennedy for the first time. The tests verified the health and status of Orion's core computers and power and data units to ensure the systems communicate precisely with one another to accurately route power and functional commands throughout the spacecraft. In spaceflight, Orion will generate power through its four solar array wings which collectively hold about 15,000 solar cells that can harness enough electricity to power eight three-bedroom homes. The power and data units then distribute that power as needed throughout the spacecraft.

Orion Thermal Testing

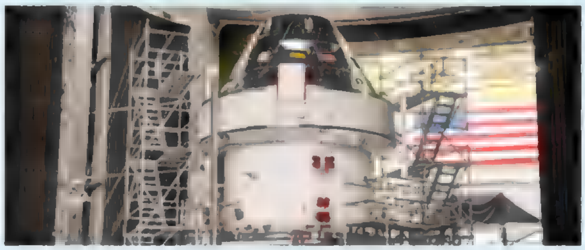


Inside a specially constructed thermal cycle chamber in the Neil Armstrong Operations and Checkout Building at Kennedy, Orion successfully completed a thermal cycle test on the crew module in February 2018. Over several days, the crew module was rapidly cycled between hot and cold temperatures to thermally stress the hardware and ensure the workmanship of the crew module's critical hardware and its subsystem operations. The cycle of temperatures for the initial thermal test ranged from 29 to 129 F during 105 hours of testing. Later that year, Orion's heat shield was secured to the bottom of the crew module.

Orion's European Service Module Delivery and Testing

In November 2018, the European-built service module that will propel, power and cool Orion during flight to the Moon on Artemis I arrived from Germany to Kennedy in the United States. In May 2019, engineers secured the service module inside a test cell and then attached microphones, strain gauges and accelerometers. They conducted a series of five tests, with acoustic levels ranging from 128 to 140 decibels—as loud as a jet engine during takeoff – to help ensure the service module is prepared to endure the noises of launch and ascent to space. From July – November 2019, engineers at Kennedy stacked Orion and its service module inside the Final Assembly and Test (FAST) cell, connecting all power and fluid lines to complete hardware attachment.

Orion Integrated Crew Module and Service Module Testing

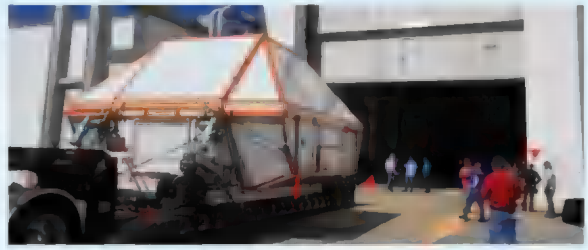


At the end of Nov. 2019, the Orion spacecraft for the first Artemis mission was delivered to Plum Brook Station for four months of rigorous simulated in-space environments testing. An international team of engineers and technicians completed the testing in two phases, beginning with a thermal vacuum test to simulate flying in and out of sunlight and shadow in space, while Orion's systems were powered on. The second phase was an electromagnetic interference and compatibility test to ensure the spacecraft's electronics work properly when operated at the same time. The test campaign was completed ahead of schedule in mid-March 2020 and confirmed the spacecraft's systems perform as designed. Orion returned to Kennedy, and will undergo a final round of testing and assembly, including end-to-end performance verification of the vehicle's subsystems, leak checks in the spacecraft's propulsion systems, installation of its solar array wings, performing spacecraft closeouts and pressurizing a subset of its tanks in preparation for flight.

Orion Simulations with Mission Control and Integrated Test Lab

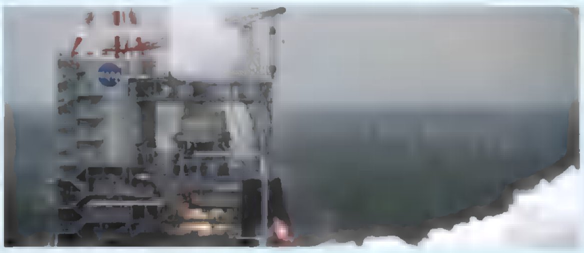
At Johnson's Mission Control Center (MCC), flight controllers simulated part of Orion's uncrewed flight to the Moon for Artemis I in June 2019. In early 2020, tests simulated launch through outbound powered flyby to the Moon, and return powered flyby from the Moon through entry, descent, and landing. Both tests were joint operations between Lockheed Martin and NASA Flight Operations allowing the teams to do real time monitoring and commanding of Orion at the Integrated Test Lab in Denver and from the MCC.

Artemis II Orion Pressure Vessel Fabrication and Delivery



The Orion pressure vessel for the Artemis II mission with crew was assembled at NASA's Michoud Assembly Facility in New Orleans. The vessel is the primary structure that holds the pressurized atmosphere astronauts will breathe and work in while in the vacuum of deep space. It consists of seven large aluminum pieces that are joined together using friction-stir welding to produce a strong, yet light-weight, air-tight capsule. The pressure vessel was loaded into the crew module transportation fixture and then lowered onto a heavy equipment semi-trailer for the nearly 700-mile journey over land to Kennedy in August 2018.

SLS RS-25 Engine Testing



Acceptance testing is complete for all 16 RS-25 engines that served as former space shuttle main engines. Tests at Stennis Space Center near Bay St. Louis, Mississippi, have shown that the engines can perform at the higher power level needed to launch the super heavy-lift SLS rocket. NASA tested the first SLS flight engine in March 2016 and completed acceptance testing in April 2019. Testing included certifying new controllers (plus one spare) to be used by the heritage RS-25 engines. Altogether, the agency has conducted 32 developmental and flight engine tests for a total of 14,754 seconds—more than four hours – of cumulative hot fire. Tests with development engines also tested new parts for future engines. Aerojet Rocketdyne made these parts with advanced manufacturing techniques, such as additive manufacturing and have the potential to increase reliability and sustainability of the engines.

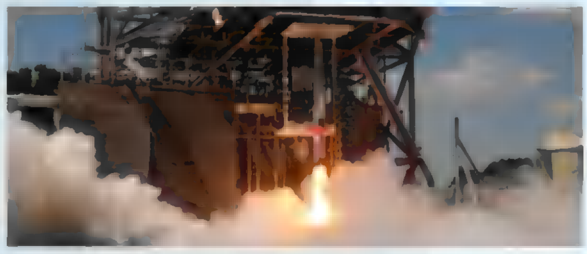
SLS Booster Testing

The SLS boosters are modeled after the space shuttle boosters but have an additional segment to provide more power and several other upgrades. The boosters completed five full-up test firings in a horizontal position with the final qualification motor test in June 2016 at Northrop Grumman's facility in in Promontory, Utah. While the boosters are using metal casings and parts that were flown on space shuttle missions, they have many new and upgraded parts including new insulation and avionics systems to control flight that have been tested at Kennedy Space Center where they are assembled and outfitted. The booster motor segments for the first two Artemis missions are assembled and ready for stacking with other booster components at Kennedy. Teams have started testing small solid rocket motors that will help the agency build next-generation solid rocket boosters for future SLS flights.

SLS Wind Tunnel Testing

The SLS team has completed extensive wind tunnel testing at NASA's Ames Research Center in Moffett Field California, Langley, and Marshall. These tests use scale rocket models to study how the vibration, base heating, and other environments affect the launch vehicle designs for both the Block 1 and Block 1B SLS configurations.

SLS Acoustic Testing

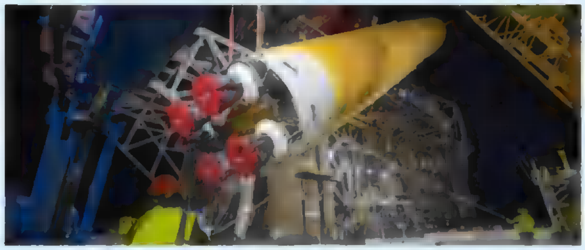


Researchers at Plum Brook Station completed a development test on a proposed design of acoustic panels for the SLS Universal Stage Adapter. The adapter will connect SLS and Orion on the future configurations of the rocket and provide additional cargo space. Given the extreme sound produced by the world's most powerful rocket, this test series, conducted at Plum Brook's Reverberant Acoustic Test Facility, provided data for acoustic modeling to ensure future payloads aboard the second configuration of SLS, called Block 1B, are protected from the high levels of noise and vibration experienced during launch. Even the Block 1 configuration of the rocket generates significant acoustic vibrations. Acoustic testing with a full-scale model of the SLS Block 1 was conducted early in the program at Marshall.

SLS Structural Testing

Engineers at Marshall completed structural testing on the 212-foot core stage and the upper part of the rocket, which includes the stage that sends the Orion spacecraft to the Moon. These tests help verify models showing the structural design can survive flight. The core has five main structures that have all undergone extensive testing. Structural testing is complete for three of the four largest structures: the engine section, the intertank, and the liquid hydrogen tank. The liquid oxygen tank has completed baseline testing. In May 2017, the parts of the rocket that make up the upper part of the rocket for Artemis I completed integrated structural testing. This included the Interim Cryogenic Propulsion Stage (ICPS), the launch vehicle stage adapter and the Orion stage adapter, as well as a frangible joint assembly. The adapters connect the parts of the vehicle, and the ICPS powered by one RL10 engine helps send Orion to the Moon. Both the ICPS and the RL10 have served on numerous flights of the United Launch Alliance Delta IV rocket with the RL10 just completing its 500th flight, and both have completed extensive testing.

SLS Core Stage Green Run Testing

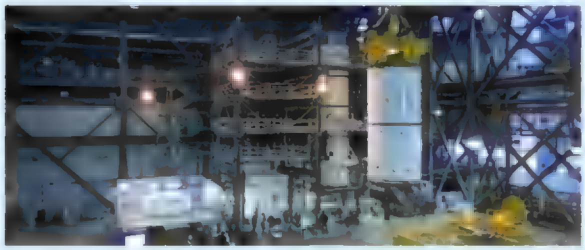


The four Artemis I RS-25 engines are attached to the core stage, manufactured by Boeing, which was delivered to Stennis in January 2020 and is undergoing Green Run testing, a thorough checkout of the new rocket stage that has never flown before. Green Run testing will culminate with firing all four engines at the same time, just as they will operate during launch. There are eight test cases that make up Green Run testing. Teams completed the first test in January 2020, before pausing test operations in March due to the coronavirus pandemic. After resuming testing in May, teams have steadily progressed through the test cases, completing the fifth test in September, and preparing for a hot fire test in the fall.

SLS Flight Software and Avionics Testing

The core stage flight computers and avionics are distributed throughout the rocket and have undergone extensive qualification testing in a laboratory and will now be tested during the Green Run. Flight software for the avionics is in the final phase of testing in a systems integration laboratory that uses avionics identical to flight hardware. The flight software has been tested by flying thousands of simulated launches and flights replicating both nominal and contingency operations. Avionics testing has been completed for the other SLS propulsion element that launches the rocket, the twin solid rocket boosters.

SLS Pathfinder Practice



In 2019, engineers and technicians practiced offloading, maneuvering and stacking the 212-foot-long SLS core stage using a full-scale mock-up called a pathfinder. In January 2020, engineers, technicians and crane operators practiced lifting and stacking operations with pathfinder segments of Northrop Grumman's solid rocket boosters inside High Bay 4 of the Vehicle Assembly Building (VAB) at Kennedy. More booster pathfinder operations are planned before the arrival of flight hardware this summer.

SLS Testing and Progress on Artemis II and Future Missions

Boeing has built all the structures for the second core stage for Artemis II and they are being outfitted at NASA's Michoud Assembly Facility in New Orleans. The liquid hydrogen tank for Artemis III is built. Both the initial and evolved designs of SLS use the core stage and boosters. Much of the testing used to qualify these elements for Artemis I also applies to future flights. For Artemis II, the booster motor segments and RS-25 engines are also completed. The booster aft and forward skirts must be refurbished and outfitted at the Booster Fabrication Facility at Kennedy. The upper part of the rocket for Artemis II consisting of the Interim Cryogenic Propulsion Stage (ICPS), the Orion Stage Adapter (OSA) and the Launch Vehicle Stage Adapter (LVSA) are being manufactured in Alabama. For Artemis I, both the OSA and ICPS are at Kennedy, and the LVSA is nearly complete and will shipped to Kennedy later this year.

Mobile Launcher and Launch Pad 39B

The mobile launcher—the 380-foot-tall ground structure that will be used to assemble, process and launch SLS – has gone through a series of tests both in the VAB and Launch Pad 39B at Kennedy. Crawler Transporter 2 (CT2) completed a test rollout of the mobile launcher for integrated testing at newly renovated Launch Pad 39B, validating it can communicate effectively with the facility systems and ground systems to perform appropriately during launch. These multi-element verification and validation tests included testing the sound suppression system, loading the cryogenic fuel system, a simultaneous umbilical swing test, and more. CT2 returned the mobile launcher to the VAB for modal testing with the mobile launcher sitting on the mount pedestals as well as with CT2 sharing the load. Exploration Ground Systems also conducted a six-hour pressurization test of the liquid oxygen tank at Launch Pad 39B, which has been upgraded for the SLS rocket. SLS will use both liquid oxygen and liquid hydrogen propellants. An initial test of xenon lights took place with the mobile launcher on the pad in October 2019, and additional lighting plans are in design.

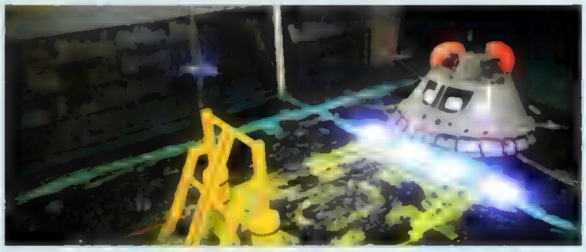
Simulated Propellant Loading

In August 2019, technicians at Kennedy simulated loading propellants into a replicated test tank for Orion, including putting on the Self-Contained Atmospheric Protective Ensemble (SCAPE) suits. SCAPE suits are used in operations involving toxic propellants and are supplied with air either through a hardline or through a self-contained environmental control unit. After donning the suits, the technicians completed a tanking to test the system before Orion arrives for processing. During preparations for launch, these teams will be responsible for loading the Orion vehicle with propellants prior to transportation to the VAB, where it will be secured atop the SLS rocket.

Launch Control Center Simulations

The Artemis I launch team at Kennedy is conducting a series of simulations to test critical portions of the countdown to ensure everyone is ready to handle any situation launch day throws their way. Under the leadership of Launch Director Charlie Blackwell-Thompson, the team is testing cryogenic loading, terminal count and other portions of the launch software currently in the final phases of development. Firing Room 1 in the Launch Control Center has been upgraded for SLS and Orion. Advances in computer and software systems [illegible] well [illegible] swapping copper cables for fiber optics change the way workstations are configured compared to the shuttle and Apollo eras. This allows greater situational awareness by the launch controllers, and reduces the number of controllers needed on launch day.

Recovery Testing at Sea



A joint NASA and Department of Defense team continues training at sea to improve landing and recovery operations for the Orion spacecraft and crew following future deep space exploration missions. Navy dive teams train at Johnson's Neutral Buoyancy Lab before joining the rest of the team in the Pacific Ocean for tests at sea. The Landing and Recovery team, led by Exploration Ground Systems at Kennedy, completed the eighth in [illegible] series of nine tests at sea in March 2020. The team is preparing for their final certification run in 2021 to ensure they are ready for splashdown of Orion after the Artemis I mission.

APPENDIX 5: Artemis Plan Funding Requirements

NASA's Artemis program will lead humanity back to the Moon and prepare for the human exploration of Mars. This lunar exploration strategy has two main components working simultaneously: 1) a near-term focus on achieving the initial human landing by 2024 as efficiently as possible with acceptable technical risk and 2) the build-up of sustainable systems, informed by our initial missions, that will allow America's human spaceflight program to maintain a robust lunar presence well into the next decade. NASA refers to these as Artemis Phase 1 and Artemis Phase 2 respectively. In addition to these two areas of Artemis, a third area of mission support spans the entire endeavor. Mission support includes the NASA capabilities, workforce, and facilities that are critical to the success of Artemis. This appendix provides a summary of the resources required through FY 2025. These resource requirements are consistent with the President's FY 2021 budget request for NASA.

Activities to enable the return of humans to the Moon by 2024

This estimate includes requested funding for Exploration Systems Development Programs, Artemis I-III flights, development and operation of the human landing system (HLS), lunar surface suits and logistics. Additionally, the estimate includes Exploration Technologies, and the Science Mission Directorate's Lunar Discovery and Exploration.

Exploration Systems Development (ESD): ESD's mission is to develop the launch vehicle, spacecraft, and ground support systems necessary to send crew beyond low-Earth orbit (LEO). ESD consists of three programs: Orion, Space Launch Systems (SLS), and Exploration Ground Systems (EGS). The Orion spacecraft will carry humans beyond LEO, provide emergency abort capability, sustain the crew during space travel, and provide safe re-entry from deep space. The SLS will be the most powerful rocket ever built and the only rocket that can send crew in Orion with its life support systems to the Moon on a single mission. EGS develops and operates the systems and facilities needed to process and launch rockets and spacecraft during assembly, transport, and launch. In preparation of Artemis III mission to the lunar system in 2024, NASA is conducting additional testing on early Artemis missions. The Artemis I (uncrewed) mission will verify spacecraft performance and test Orion's head shield, whereas the Artemis II (crewed) will validate deep space communication and navigation systems and ensure the resilience of life support systems.

Human Landing Systems (HLS): The HLS program will utilize commercial partnerships to develop and jointly deploy a landing system to transport humans to and from the lunar surface. NASA expects its commercial partners will heavily leverage NASA technology and expertise throughout the development process, leading to a lunar transportation system that will deliver humans to the lunar surface in 2024, and develop and demonstrate a more sustainable HLS for subsequent crewed missions.

Surface Suits (maintained in Gateway Budget): NASA is developing the Exploration EMU (xEMU) spacesuit system capable of supporting spacewalks both on the surface of the Moon and in microgravity environments. The crew will wear the xEMU as they explore the surface for up to seven days before returning to Orion for the trip home to Earth. This activity's funding is maintained within the Gateway budget.

Surface Logistics (maintained in ACSC Budget): NASA is working to develop the mechanisms necessary to deliver the supplies necessary to support Artemis Mission on the Lunar Surface. This activity's funding is maintained within the Advanced Cislunar and Surface Capabilities (ACSC) Budget

Exploration Technologies: Exploration Technology serves as a catalyst for the new technology required to "lead the return of humans to the Moon for long-term exploration and utilization" (Space Policy Directive-1). Through the Exploration Technology account, the Space Technology Mission Directorate (STMD) funds this critical technology research and development to support the 2024 lunar landing and the long-term success of the Artemis Moon to Mars campaign. These Artemis Phase 1 efforts enable technology research and development needs for human space exploration with a near-term focus on technology development priorities such as: autonomous operations, dust mitigation, and extreme environment technology. STMD aims to deliver the Solar Electric Propulsion in support of the Power and Propulsion Element of Gateway, develop technologies for Precision Landing and cryogenic fluid management.

Science Element - Lunar Discovery and Exploration Program (LDEP): LDEP in the Science Mission Directorate is a key component of the NASA's Exploration Strategy. It includes the establishment of commercial contracts for lunar landing transportation services; the development of instruments that serve lunar science; long-term exploration and utilization needs; the development of smallsats

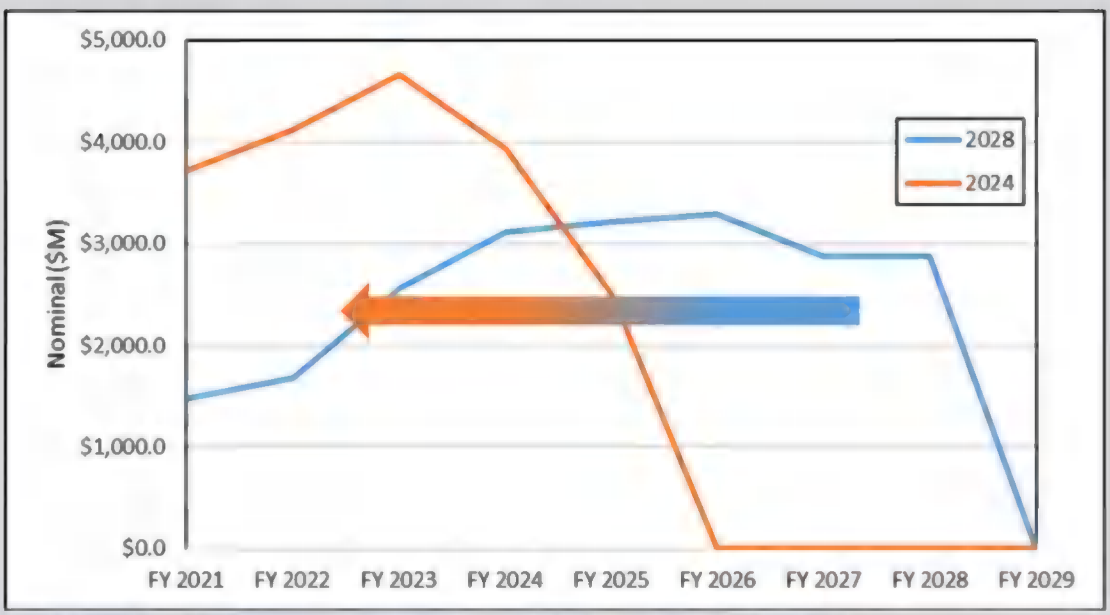
that will provide innovative investigations; continued operations of the Lunar Reconnaissance Orbiter; and, the development of long-duration lunar rovers that will utilize commercially developed landers to get to the lunar surface. NASA is prioritizing capabilities that support lunar resource analysis and prospecting to inform future human spaceflight objectives and includes activities for Commercial Lunar Payload Services and the Volatiles Investigating Polar Exploration Rover (VIPER). LDEP funding from FY 2021 through FY 2024 is considered part of Artemis Phase 1 to support capability development prior to the Artemis III mission.

The following table provides a summary of the Artemis Phase 1 funding requirements through FY 2025 that have been addressed in the preceding discussion. While Artemis III is planned for Calendar Year 2024, Fiscal Year 2025 begins on October 1st, 2024, and FY2025 will include costs associated with Artemis III mission operations and logistics, as well as post-demonstration follow-on analysis. The Artemis Phase 1 funding plan reflects the current requirements for Phase 1 within the overall FY 2021 President's request, including current allocation of Artemis budget elements to Artemis Phase 1 and Artemis Phase 2.

$ Millions	FY2021	FY2022	FY2023	FY2024	FY2025	Total
Orion/SLS/EGS (Exploration System Development Programs)	$ 2,894.7	$ 2,070.6	$ 1,487.6	$ 919.0	252.0	$ 7,623.9
Initial Human Landing System	$ 3,222.5	$ 3,553.1	$ 4,100.4	$ 3,571.3	1,719.0	$ 16,166.4
Lunar Suits - *maintained in Gateway budget*	$ 177.3	$ 141.0	$ 94.2	$ 63.1	42.5	$ 518.1
Surface Logistics - *maintained in ACSC budget*	$ 67.6	$ 69.2	$ 141.9	$ 196.0	77.7	$ 552.4
Exploration Technologies	$ 251.0	$ 292.0	$ 268.0	$ 223.0	158.0	$ 1,192.0
LDEP – *maintained in SMD Artemis Science Elements budget*	$ 451.5	$ 517.3	$ 491.3	$ 458.3	-	$ 1,918.3
Total Phase 1 Requirements	**$ 7,064.7**	**$ 6,643.1**	**$ 6,583.4**	**$ 5,430.7**	**2,249.2**	**$ 27,971.1**

Artemis Phase 1 Funding Requirements.

Artemis Phase 1 funding requirements represent a more efficient and direct plan than NASA's previous concept of the 2028 landing. While the funding requirements are accelerated and near-term amounts have comparatively increased, overall funding requirements for the 2024 Phase 1 effort are not higher and sustained lunar presence and future exploration are accelerated.



Overall Artemis Phase 1 funding to achieve a 2024 landing is not higher than prior plans for a 2028 landing.

APPENDIX 6:
NASA's Plan for Sustained Lunar Exploration and Development

ARTEMIS

NASA'S PLAN FOR A VIBRANT LUNAR FUTURE

"Lead an innovative and sustainable program of exploration with commercial and international partners to enable human expansion across the solar system and to bring back to Earth new knowledge and opportunities. Beginning with missions beyond low-Earth orbit, the United States will lead the return of humans to the Moon for long-term exploration and utilization, followed by human missions to Mars and other destinations."

– President Trump, Space Policy Directive 1, December 11, 2017

"The NASA Administrator shall submit a plan to the Chairman of the National Space Council for sustainable lunar surface exploration and development, including necessary technologies and capabilities to enable initial human exploration of Mars."

– Vice President Pence, 6th Public Meeting of the National Space Council, August 20, 2019

OVERVIEW

The Moon is the gateway to the solar system. A world equivalent to an entire continent that human feet have touched only a few times. As Earth's nearest planetary neighbor, the Moon has profound potential to be a source of new scientific advances and economic growth. It is also the best place for us to test our deep space systems and operations in preparation for the first human mission to another planet: Mars. Over the next decade, the Artemis program will lay the foundation for a sustained long-term presence on the lunar surface and use the Moon to validate deep space systems and operations before embarking on the much farther voyage to Mars.

Over the coming decades and generations, our presence will grow to use and develop the extensive resources of the Moon, including its water and metal deposits. As the Moon unveils her secrets, scientific interest continues to grow. In addition to enabling scientific understanding of the formation of the Earth and the solar system through lunar geology and chemistry, exploration of the Moon will enable ground-breaking scientific discoveries about the universe, including through radio astronomy from the incredible vantage point of the far side of the Moon. As in the skies and now low-Earth orbit, NASA's scientific and exploration efforts lead the way and economic development follows. The Artemis program will similarly enable commercial opportunities on the lunar surface, beginning with the first U.S commercial lunar deliveries next year.

The Moon is more than a physical destination. A core focus of Artemis is to extend the nation's geo-strategic and economic sphere to encompass the Moon with international partners and private industry. The United States will build confidence among its commercial, U.S. government, and international partners by leading the development of clear policy principles to support civil space exploration with an initial emphasis on the Artemis program. Specifically, the

U.S. will establish a predictable and safe process for the extraction and use of space resources under the auspices of the Outer Space Treaty.

This document covers and responds to the Chairman of the National Space Council's direction to provide a plan for a sustained lunar presence, including the technologies and capabilities to enable the first human mission to Mars. For millennia humanity has looked at the Moon in wonder and awe. As the United States leads the development of a sustained presence on the Moon together with commercial partners and international partners, our presence on the Moon will serve as a constant reminder of the limitless potential of humanity. It will continue to inspire humanity as we seek ever more distant worlds to explore - starting with Mars.

The first human mission to Mars will mark a transformative moment for human civilization. Establishing a sustained lunar presence and taking the initial steps toward the first human mission to Mars will be the greatest feat of engineering, and the greatest voyage of exploration and discovery, in human history. These missions will drive technology and innovation using the country's unparalleled scientific capabilities, dynamic economy, and robust industrial base. These missions will inspire generations of science, technology, engineering, and mathematics (STEM) professionals and countless other disciplines, while offering opportunities to domestic partners in government, industry, and academia.

Most importantly, the accomplishments of the Moon to Mars approach will assure that America remains at the forefront of exploration and discovery. The United States is still the only nation to have successfully landed humans on the Moon and spacecraft on the surface of Mars. As other nations steadily increase their presence and spending, American leadership is now called for to lead the next phase of humanity's quest to create a future comprised of endless discovery and growth in the final frontier.

THE ARTEMIS GENERATION

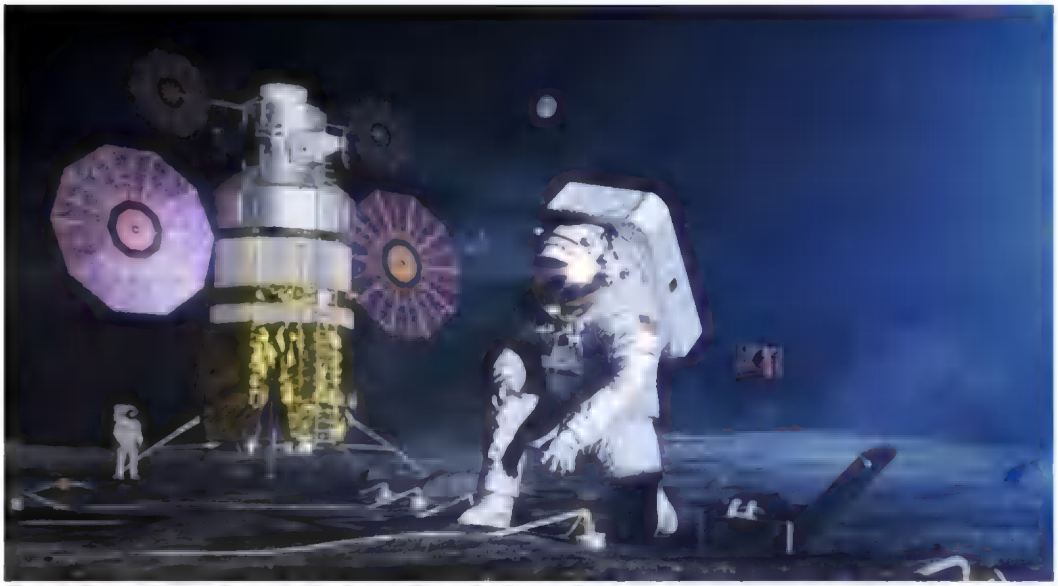


Figure 1: Concept image of an early Artemis expedition on the lunar surface.

Everyone born after the year 2000 has always known a world where people have been living in space. In this decade, we will all see humans walking on the Moon again – this is the Artemis Generation. Artemis, the twin sister of Apollo, will put in place the key infrastructure on and around the Moon that will be built upon and leveraged for generations to come.

Americans will return to the Moon in 2024. Following this 2024 landing, we will develop a sustained, strategic presence at the lunar South Pole called the Artemis Base Camp. Our activities at our Artemis Base Camp over the next decade will pave the way for long-term economic and scientific activity at the Moon, as well as for the first human mission to Mars in the 2030s.

Starting next year, a steady stream of robotic precursors and technology demonstrations will begin lunar operations. The Moon is a fundamental part of our planet's past and future. Although Americans first walked on its surface more than 50 years ago, our explorers left only fleeting footprints at a few sites, spending a total of 16 days on the lunar surface. These missions were all in the equatorial region, with a total traverse of less than 100kms (~62 miles) – on a body whose surface area is the size of Africa.

This next wave of lunar exploration will be fundamentally different. It starts with American expeditions to the vicinity of the Moon in 2023, and landing astronauts on the surface in 2024. This will be the first chance for most people alive today to witness a human lunar encounter and landing – a moment when, in awe and wonder, the world holds its breath. America will not stop there – this will be the opening chapter of a new era of discovery and exploration.

NASA'S THREE DOMAIN EXPLORATION STRATEGY

Artemis is the core of NASA's exploration and human spaceflight plans for the next decade. Artemis builds upon ongoing human spaceflight efforts conducted aboard the International Space Station (ISS) and prepares the way for future human spaceflight programs, including the first human mission to Mars. NASA's overall Level Zero Goals for exploration encompass these three primary domains – low-Earth orbit, the Moon, and Mars.

Figure 2: The transition to low-Earth orbit has already begun. Two commercial cargo vehicles, SpaceX's Dragon and Northrop Grumman's Cygnus, service the International Space Station.

NASA Exploration Level Zero Goals

- Transition U.S. human spaceflight in low-Earth orbit to commercial operations, which support NASA and its partners. Use the ISS and new commercial facilities as testbeds for exploration technologies and to nurture emerging commercial applications.
- Advance long-term robotic exploration of the Moon with robust commercial and international partnerships.
- Land American astronauts on the Moon and return them safely.
- Expand U.S. human spaceflight operations at the Moon to support sustained lunar surface activities and to demonstrate elements of a Mars-forward architecture.
- Continue U.S. leadership at Mars by advancing robotic access in preparation for human exploration.
- Engage and inspire America and the world along each step of the way.

Pursuing these goals will ensure our current and future activities in low-Earth orbit can enable Artemis, and that Artemis enables the future exploration of Mars.

NASA has developed a strategy for achieving the Level Zero Goals that includes: a combination of robotic and human missions; architectures that build off of key, enabling hardware elements already in development; new technologies that will expand future options and operations; and new developments which will engage the NASA workforce, industry, and international partners to encourage innovative capabilities and harness competitive and cooperative energies. These efforts are being integrated into a sequence of missions that start with a near-term return of humans to the Moon, and then continue with a set of missions on and around the Moon that will lay the foundation for a sustainable presence. Ultimately, the experiences gained, and technologies demonstrated by these lunar operations will support a historic first human mission to Mars. Conducting scientific exploration synergistically with crew and robotic explorers teaches us effective techniques that can be applied as we push the boundaries of space exploration.

ROBOTIC MISSIONS

Our return to the Moon begins with robots. For more than a decade, NASA's Lunar Reconnaissance Orbiter has been imaging and mapping the Moon for scientific research and in preparation for a human return. NASA's new Commercial Lunar Payload Services (CLPS) initiative has already selected the first two robotic missions that, beginning in 2021, will deliver science and commercial payloads to the surface of the Moon. NASA has also committed to using this approach to deliver its next robotic lunar rover, the Volatiles Investigating Polar Exploration Rover (VIPER), which will conduct science investigations of the lunar volatiles at the Moon's South Pole. The data produced by VIPER will inform future in-situ resource utilization (ISRU) technologies. On the lunar surface we will demonstrate precision landing, starting with CLPS deliveries to build experience and improve capabilities that will enhance all future landings, human and robotic. Later, the CLPS approach will be used to deliver other large cargo elements in direct support of human lunar missions.

Overall, while orbital missions have provided extensive information about the lunar surface and its potential resources, robotic lunar surface scouts are essential to validate these observations and prepare for human habitation and utilization of the Moon's rich array of resources from volatiles to minerals. Landers and rovers provide excellent platforms to demonstrate technologies that will enable greater lunar surface mission capabilities and have applications that extend beyond the Moon to Mars initiative, such as terrestrial robotic mining systems and next-generation power storage. Multiple landers will provide a global view of the Moon and its resources. Rovers will be used to explore the surface more extensively, carrying a variety of instruments including ISRU experiments that will generate detailed information on the availability and extraction of usable resources (e.g., oxygen and water).

These robotic efforts will unleash a broad array of inquiry and scientific investigations. The Moon is a natural laboratory to study planetary processes and evolution, and a platform from which to observe the universe. Bombarded by solar and cosmic radiation for billions of years

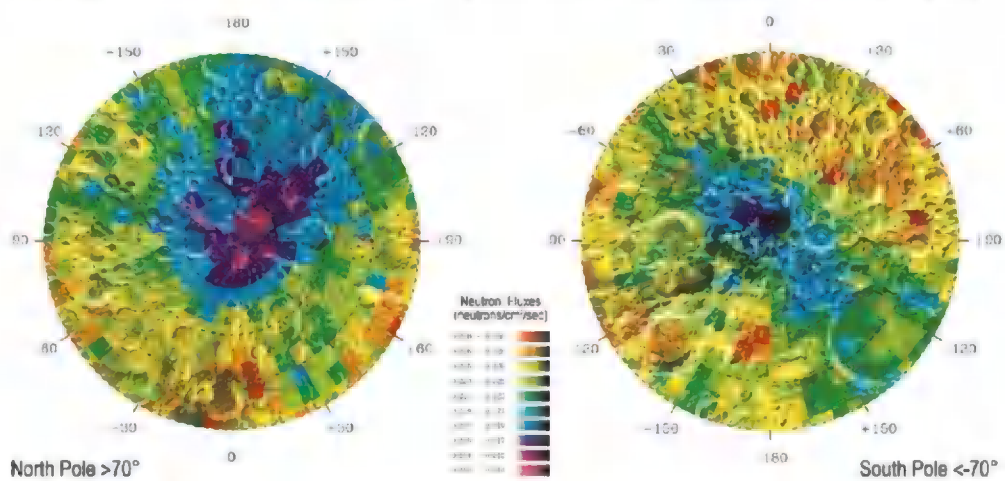


Figure 3: Image Above: The dark blue and purple areas at the Moon's poles indicate neutron emissions that are consistent with hydrogen-rich deposits covered by desiccated regolith. These hydrogen signatures are possible indications of water in the form of water or hydrated minerals. Feldman et al., Science, 281, 1496, 1998.

and left largely undisturbed, the Moon is a historic archive of our Sun and solar system. Scientific discoveries are locked in its regolith that could lead to improved understanding of our own planet and its evolution. The far side of the Moon offers an unparalled window to look back into the beginning of the universe. It also harbors resources, such as water, that are among the rarest and most precious commodities in space, offering potential sustenance and fuel for future explorers.

THE EARLY ARTEMIS MISSIONS


Figure 4: Concept image of the Space Launch System launching from Kennedy Space Center

The foundation for our return to the Moon is NASA's Orion spacecraft and Space Launch System (SLS). The Orion spacecraft has been designed for deep space operations around the Moon for up to four crew members, and the SLS is the powerful heavy-lift rocket designed to launch it, and potentially other high-mass cargo to the lunar environment. Added to these are the two newest elements of the lunar return architecture under contract, the power and propulsion element (PPE) and the habitation and logistics outpost (HALO). Together they form the Gateway's foundation as the Artemis lunar orbiting platform. Early Gateway operations will be autonomous, with help from NASA's Mission Control Center at Johnson Space Center in Houston to conduct systems checkouts and capture critical scientific data about the deep space environment. Orion will deliver the first crew to Gateway when the human landing system (HLS) capability can enable lunar expeditions to be staged from the stable Gateway orbit. Building confidence in this system of an orbiting command module and deployable landers will serve as a critical analog for human missions to the surface of Mars. It will also serve as a strategic capability – allowing access and presence in the orbital lanes around the Moon and to the rest of the solar system.

The Artemis program begins with an uncrewed flight test of the SLS and Orion (Artemis I), then a crewed flight test (Artemis II). Artemis I will see SLS send an uncrewed Orion 280,000 miles from Earth, thousands of miles beyond the Moon over the course of an approximately three-week mission. Mission controllers on Earth will collect data to assess the performance of both spacecraft. This mission will also deploy 13 CubeSats that will conduct new scientific investigations and new technology demonstrations that will engage a broader set of universities and companies in lunar exploration than ever before on a single mission.

With the first crewed flight test of the SLS and Orion, Artemis II, astronauts will return to the vicinity of the Moon for the first time in more than 50 years. This will be an Apollo 8 moment for a new generation. At the end of this mission, NASA intends to have tested every hardware, software, and operational component of Artemis III *except* for the actual landing on the surface.

Artemis III will be the culmination of the rigorous testing and nearly one million miles of flight demonstrations on the deep space transportation systems that NASA will accumulate during Artemis I and II. When Artemis III lands the first woman and next man on the Moon in 2024,

America will have demonstrated a new level of global space leadership. With this robust lunar exploration capability re-established, NASA and the world will focus on building a sustained presence on the lunar surface in preparation for long-term development on the Moon and the human exploration of Mars.

The Gateway will establish U.S. leadership and a sustained presence in the region between the Moon and Earth. The platform will offer astronauts easier crew returns, a safe haven in the event of an emergency, the ability to navigate to different orbits around the Moon and later, an advancement in human life support systems.

Gateway will expand to include critical contributions from international partners, specifically, a robotic arm, substantial additional habitation volume, and refueling capabilities. Canada announced in February 2019 that it intends to participate in the Gateway and contribute advanced external robotics. In October 2019, Japan announced plans to join the United States on the Gateway with contributions to habitation components and logistics resupply. In November 2019, the European Space Agency received authorization and funding to support its planned contributions to the Gateway, the International Habitat (I-Hab), and the European System Providing Refueling Infrastructure and Telecommunications (ESPRIT), both of which will dramatically enhance the capabilities of Gateway, contributing to sustainable operations while paving the way for a future human mission to Mars. Russia has also expressed interest in cooperating on the Gateway via the contribution of an airlock. The Gateway will provide a next-generation deep space platform from which to conduct science investigations outside the protection of the Earth's Van Allen radiation belts. The international science community has identified heliophysics, radiation, and space weather as high-priority investigations to conduct on the Gateway. The first two Gateway payloads are a radiation instrument package provided by the European Space Agency and a space weather instrument from NASA. The agency also recently awarded the first Gateway Logistics Services (GLS) contract to SpaceX to deliver cargo, experiment and other supplies to the outpost. Echoing the success of the Commercial Resupply Services program, GLS will leverage commercial partners to deliver logistics to the Gateway, supporting lunar operations while building experience and technologies for future logistics missions that can support the first human mission to Mars.

With these core elements, logistics support, and flights of SLS/Orion underway, and the acquisition of HLS in progress, NASA is opening up other core elements of a sustained lunar presence – including the lunar terrain vehicle (LTV), the lunar mobile habitat or habitable mobility platform, the lunar foundation surface habitat (FSH), power systems, lunar ISRU systems, and expanded Gateway habitation capabilities – with new international and industry partnerships. With this approach, NASA will leverage years of hard work and national investment in the systems needed to return to the Moon, while enabling and using new partners and new capabilities to ensure that our return to the Moon is sustainable and leads directly to the first human mission to Mars.

ARTEMIS AFTER 2024

After Artemis III, the overall plan is to conduct operations on and around the Moon that help prepare us for the mission durations and activities that we will experience during the first human mission to Mars, while also emplacing and building the infrastructure, systems, and robotic

missions that can enable a sustained lunar surface presence. To do this, we will develop Artemis Base Camp at the South Pole of the Moon.

Artemis Base Camp will be our first sustainable foothold on the lunar frontier. We will initially move to one to two-month stays to learn more about the Moon and the universe. We will develop new technologies that advance our national industries and discover new resources that will help grow our economy. Overall, the base camp will demonstrate America's continued leadership in space and prepare us to undertake humanity's first mission to Mars.

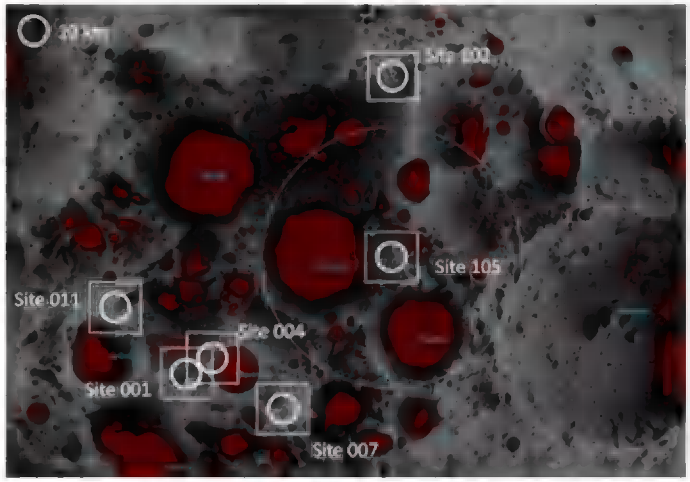


Figure 5: A South Pole landing site has not been determined, but this image shows sites of interest near permanently shadowed regions, which may contain mission-enhancing volatiles. These sites may also offer long-duration access to sunlight, direct-to-Earth communication, surface slope and roughness that will be less challenging for landers and astronauts.

The three primary mission elements of Artemis Base Camp are: The LTV that can transport crew around the site; the habitable mobility platform for long-duration trips away from Artemis Base Camp and the foundation surface habitat will enable short-stays for four crew on the lunar South Pole. Combined with supporting infrastructure added over time such as communications, power, radiation shielding, a landing pad, waste disposal, and storage planning – these elements comprise a sustained capability on the Moon that can be revisited and built upon over the coming decades.

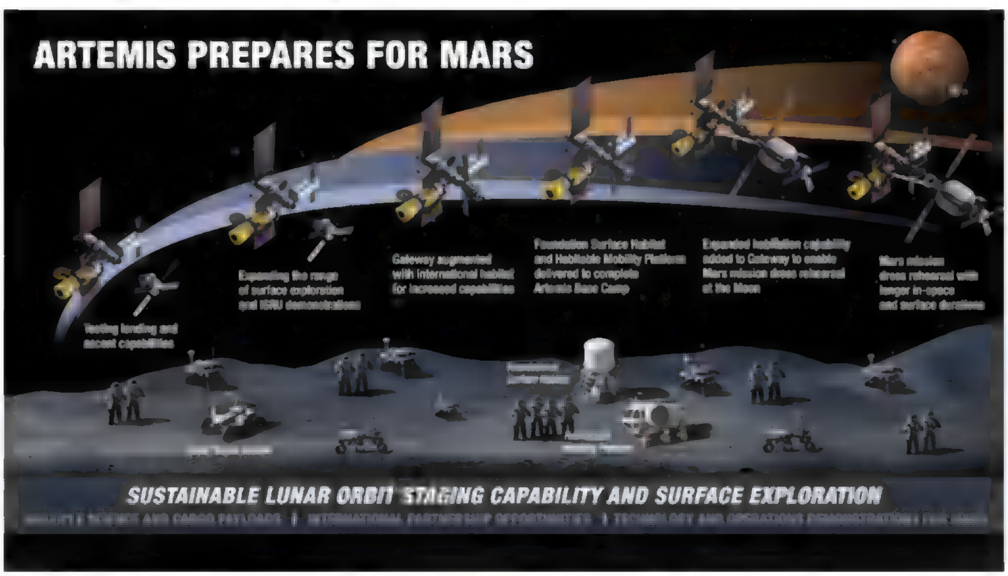


Figure 6: Artemis Base Camp evolves on the surface as the Gateway is leveraged for Mars preparation.

Mobility is a major part of the Artemis Base Camp. The LTV and the habitable mobility platform will enable long-term exploration and development of the Moon. In addition to its size, the Moon's geography is complex, and its resources dispersed. Looking at potential sites for Artemis Base Camp, such as near Shackleton Crater, shows the immense scale of the lunar geography. Robust mobility systems will be needed to explore and develop the Moon. The same is true for Mars, making the habitable mobility platform a particularly important element as we will need a similar type of vehicle to explore the Red Planet.

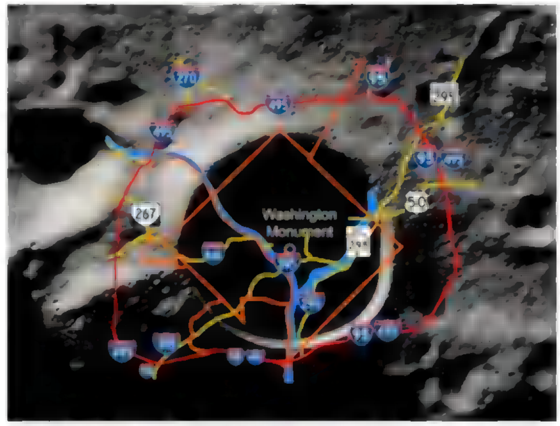


Figure 7: The lunar South Pole's Shackleton Crater, as captured by the Lunar Reconnaissance Orbiter, with the Capital Beltway overlaid for scale.

In addition to establishing Artemis Base Camp, another core element of the sustained lunar presence that feeds forward to Mars will be the expansion of habitation and related support systems at the Gateway. This evolution of the Gateway's systems to include large-volume deep space habitation would allow our astronauts to test, initially in lunar orbit, how they will live on their voyage to and from Mars. Gateway can also support our first Mars mission analogs on the lunar surface. For such a mission, we currently envision a four-person crew traveling to the Gateway and living aboard the outpost for a multi-month stay to simulate the outbound trip to Mars, followed by two crew travelling down to and exploring the lunar surface with the habitable mobility platform, while the remaining two crew stay aboard. The four crew are then reunited at the Gateway for another multi-month stay, simulating the return trip to Earth, before landing


Figure 8: Orion approaches an evolved Gateway.

back home. These missions will be by far the longest duration human deep space missions in history. They will be the first operational tests of the readiness of our long-duration deep space systems, and of the split crew operations that are vital to our approach for the first human Mars mission.

There are many factors associated with the sequence of element development, testing, and launch such as capability maturity and availability, budget, launch vehicle availability, and system complexity. For planning purposes, NASA is developing a sequence that accounts for these variables and results in an annual cadence of demonstrable progress and a gradual increase in mission duration and complexity. This plan results in the development and emplacement of the infrastructure required for a long-term sustained lunar surface presence while testing systems and gaining the operational experience required for the human Mars mission.

The sequence as currently envisioned begins by sending lunar precursor robotic missions including VIPER by CLPS landers to provide ground truth of terrain, as well as water and metal resource availability for the human lunar landing site. To provide mobility and extended range of exploration for the first several human lunar surface missions, the LTV will be delivered to the lunar surface. The first elements of the lunar Gateway are in development and will support later sustainable human lunar landing missions. NASA anticipates its international partners will provide at a minimum the robotic arm, I-Hab, and ESPRIT to supplement the Gateway's capabilities in lunar orbit.

The habitable mobility platform will be delivered to the lunar surface to expand our exploration range by tens of kilometers and mission duration on the surface from 7 days to 30-45 days, enabling potential Mars surface analog missions on the lunar surface. Other key pieces of the Artemis Base Camp infrastructure are also delivered, including the foundation surface habitat, which will support a crew up to four on the lunar surface, the lunar surface power systems, ISRU demonstrations and pilot plants.

An evolved Gateway habitation capability in lunar orbit will allow us to begin the methodical lengthening of mission durations. This approach will also allow NASA to test risk mitigation approaches for long-duration mission crew and element systems risks that are required for two-year Mars class missions.

Once these pieces of the Moon to Mars campaign are delivered and operational, annual human missions with increasingly long durations will enhance the exploration and sustainable development of the lunar surface.

A VIBRANT EARTH-MOON FUTURE

Whenever the first human mission to Mars occurs, it will not mean that we are done with the Moon. The windows for launching the two-year mission to Mars open up every few years, and we will continue to conduct human missions to the lunar surface to test systems, conduct scientific investigations, and continue to develop our sustainable lunar presence as we prepare for the optimal launch window.

We will continue to explore the Moon indefinitely -- leveraging robotic deliveries provided by CLPS providers, longer duration human missions, and commercial and international

partnerships that will add to the Artemis Base Camp elements NASA puts in place. The LTV, habitable mobility platform and foundation surface habitat will stay on the Moon enabling crews to live on the lunar surface for months at a time. The rovers and crew-tended capabilities on the Moon will be designed to operate autonomously and to work with independent robotic assistants.

In addition to testing our systems for the first mission to Mars, a core purpose of Artemis Base Camp will be to demonstrate new technologies that, over time, will expand our capabilities and reduce the costs of lunar operations. Astronauts at Artemis Base Camp will be testing a wide set of new technologies in six priority areas encompassed by the recently announced Lunar Surface Innovation Initiative (i.e. ISRU; surface power; extreme access; excavation and construction; lunar dust mitigation; and extreme environments). Some of these technologies will help from the beginning, such as lunar dust mitigation and enabling operations in extreme environments like the cold of the lunar night. Other technologies are in early development for significant long-term benefits. For example, ISRU will enable the production of fuel, water, and/or oxygen from local materials, enabling sustainable surface operations with decreasing supply needs from Earth. For surface power, our goal is to develop advanced solar collection and a small, lightweight fission power system to support even longer-duration missions and operations on the Moon, and eventually for Mars and beyond. Autonomous manufacturing, excavation, and construction technologies will make infrastructure emplacement more affordable.

Astronauts will also conduct tests of advanced robotics, including future biomimetic systems that enable more autonomous operations at the Moon and can serve as robotic assistants to the crew. In time, Artemis Base Camp might also include a hopper that could deliver science and technology payloads all over the Moon and which could be operated by crew at Artemis Base Camp and refueled using locally sourced propellant. A lunar far-side radio telescope could also be remotely emplaced and operated from Artemis Base Camp – a sort of backyard radio-telescope at our first encampment on the Moon.

Developing a sustained and vibrant lunar presence will not only require the best of NASA and its international partner space agencies, but also the best of the entire U.S. government and commercial sector. Establishing the infrastructure that will enable additional international and commercial partnerships will result in opportunities for the first international and commercial astronauts on the lunar surface, opening up Earth's 's off-shore continent for ongoing human discovery and development. NASA's unique leadership and capabilities will be combined with innovation and contributions from the same sectors that fuel our nation and economy here on Earth.

THE INITIAL HUMAN MARS MISSION

The success of the first human mission to Mars requires a voyage of stunning technological and operational complexity. The distance from Earth to the Moon is a relatively manageable 250,000 miles. In contrast, Mars is, on average, 140 million miles from Earth. The challenges of a mission to Mars are compounded not only by these distances but by the more dangerous levels and types of radiation that is found in deep space. Mars' atmosphere – while intriguing from a scientific perspective – also presents distinct challenges for getting humans to and from its surface.

The initial lunar missions will greatly inform our concept of operations for Mars. Every day in deep space increases the probability of catastrophic events occurring. The concept of operations NASA is working toward for the first human mission to Mars is therefore one that reduces trip time significantly and minimizes time spent on the surface to around 30-45 days. Factors NASA will continue to consider include: risks to crew health during transit, both from galactic cosmic ray (GCR) radiation and from potential catastrophic mission events; the complexity of mission operations on the Martian surface; and the complexity and cost of mission systems, such as in-space propulsion, the ability to land heavy payloads, and required surface systems. NASA has targeted conducting a human mission to Mars that can be realized as soon as possible, while still ensuring that our Mars surface capabilities will allow for extensive exploration on our first mission, including a search for Martian life. The Moon will allow us to test and demonstrate significant parts of this mission before sending humans on this epic journey. NASA will have more to share on the strategy for how the Moon prepares us for the first human mission to Mars in the coming months.

Artemis and the development of Artemis Base Camp will inspire the world with the ability and commitment of American leadership, and in the positive potential of humanity as a whole. If we are to leave a legacy of greatness, hope, limitless opportunity, and growth to future generations, then it is a mission we cannot afford to postpone.

APPENDIX 7:
The Artemis Accords

Principles for a Safe, Peaceful, and Prosperous Future

Via the Artemis program, NASA will land the first woman and the next man on the Moon by 2024, heralding in a new era for space exploration and utilization.

While NASA is leading the Artemis program, international partnerships will play a key role in achieving a sustainable and robust presence on the Moon while preparing to conduct a historic human mission to Mars.

With numerous countries and private sector players conducting missions and operations in cislunar space, it's critical to establish a common set of principles to govern the civil exploration and use of outer space.

International space agencies that join NASA in the Artemis program will do so by executing bilateral Artemis Accords agreements, which will describe a shared vision for principles, grounded in the Outer Space Treaty of 1967, to create a safe and transparent environment which facilitates exploration, science, and commercial activities for all of humanity to enjoy.

Peaceful Uses

International cooperation on Artemis is intended not only to bolster space exploration but to enhance peaceful relationships between nations. Therefore, at the core of the Artemis Accords is the requirement that all activities will be conducted for peaceful purposes, per the tenets of the Outer Space Treaty.

Transparency

Transparency is a key principle for responsible civil space exploration and NASA has always taken care to publicly describe its policies and plans.

Artemis Accords partner nations will be required to uphold this principle by publicly describing their own policies and plans in a transparent manner.

Interoperability

Interoperability of systems is critical to ensure safe and robust space exploration.

Therefore, the Artemis Accords call for partner nations to utilize open international standards, develop new standards when necessary, and strive to support interoperability to the greatest extent practical.

Emergency Assistance

Providing emergency assistance to those in need is a cornerstone of any responsible civil space program.

Therefore, the Artemis Accords reaffirm NASA's and partner nations' commitments to the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space.

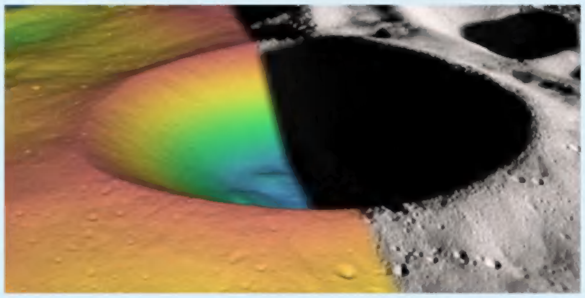
Additionally, under the Accords, NASA and partner nations commit to taking all reasonable steps possible to render assistance to astronauts in distress.

Registration of Space Objects

Registration is at the very core of creating a safe and sustainable environment in space to conduct public and private activities. Without proper registration, coordination to avoid harmful interference cannot take place.

The Artemis Accords reinforces the critical nature of registration and urges any partner which isn't already a member of the Registration Convention to join as soon as possible.

Release of Scientific Data



NASA has always been committed to the timely, full, and open sharing of scientific data.

Artemis Accords partners will agree to follow NASA's example, releasing their scientific data publicly to ensure that the entire world can benefit from the Artemis journey of exploration and discovery.

Protecting Heritage

Protecting historic sites and artifacts will be just as important in space as it is here on Earth.

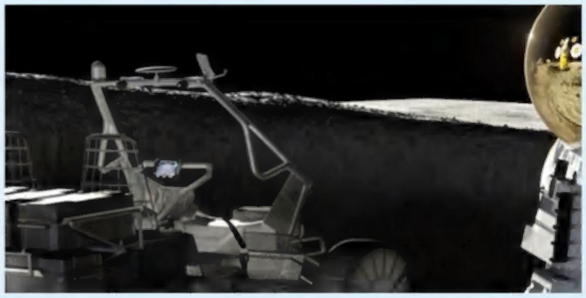
Therefore, under Artemis Accords agreements, NASA and partner nations will commit to the protection of sites and artifacts with historic value.

Space Resources

The ability to extract and utilize resources on the Moon, Mars, and asteroids will be critical to support safe and sustainable space exploration and development.

The Artemis Accords reinforce that space resource extraction and utilization can and will be conducted under the auspices of the Outer Space Treaty, with specific emphasis on Articles II, VI, and XI.

Deconfliction of Activities



Avoiding harmful interference is an important principle of the Outer Space Treaty which is implemented by the Artemis Accords.

Specifically, via the Artemis Accords, NASA and partner nations will provide public information regarding the location and general nature of operations which will inform the scale and scope of "Safety Zones".

Notification and coordination between partner nations to respect such safety zones will prevent harmful interference, implementing Article IX of the Outer Space Treaty and reinforcing the principle of due regard.

Orbital Debris and Spacecraft Disposal

Preserving a safe and sustainable environment in space is critical for both public and private activities.

Therefore, under the Artemis Accords, NASA and partner nations will agree to act in a manner that is consistent with the principles reflected in the Space Debris Mitigation Guidelines of the United Nations Committee on the Peaceful Uses of Outer Space.

Moreover, NASA and partner nations will agree to plan for the mitigation of orbital debris, including the safe, timely, and efficient passivation and disposal of spacecraft at the end of their missions.

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